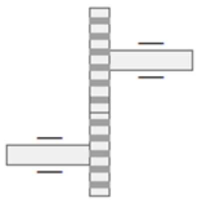
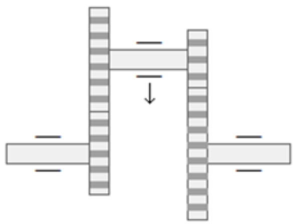
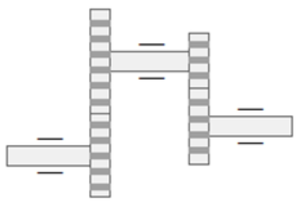
11. Category Mechanics

11.1. Gear Ratio

11.1.1. Purpose (What can it be used for? What can it not be used for?)

The program is part of category 6 – mechanics. Sometimes it is required to retrace the function of installed gear sets in order to be able to carry out functional checks respectively to determine or exclude error sources. Therefore the program provides six different basic gear sets. These are:

Type 1: single-step gear set		2 x gear wheel 2 x diameter 2 x rotation 2 x torque 2 x power rate 1 x transmission rate 1 x efficiency
Type 2: multi-step gear set		4 x gear wheel 4 x diameter 3 x rotation 3 x torque 3 x power rate 1 x transmission rate 1 x efficiency
Type 3: planetary gear set		4 x gear wheel 1 x rack 5 x diameter 3 x rotation 3 x torque 1 x power rate 1 x transmission rate

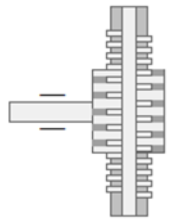
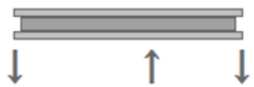
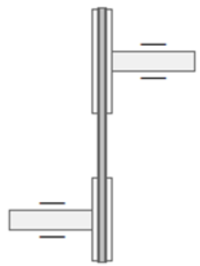
Type 4: worm gear set		1 x gear wheel 1 x diameter 1 x shaft 1 x distance 2 x rotation 2 x torque 2 x power rate 1 x transmission rate 1 x efficiency
Type 5: rocker		2 x lever 2 x force 1 x torque 1 x transmission rate
Type 6: belt gear set		2 x gear wheel 1 x belt 2 x diameter 2 x rotation 2 x torque 2 x power rate 1 x transmission rate 1 x efficiency

Figure 134: sketches gear ratio – Table with Type1 to 6

The relevant variables for the calculations are in the first the rotation frequency and the torque. The mechanical power rate results out of these two variables. Losses due to friction, unbalances etc. cause that the power rate cannot be kept constant in practice. So the power rate at the outlet is always less than the power rate at the inlet of the gear set. This is simulated by the efficiency, which is given as a percentage value. The inlet power rate multiplied by the efficiency results the outlet power rate. The consideration of the efficiency can be activated or deactivated left side from the value. In case if the efficiency is deactivated, the value is set to 100%, which means a constant power rate is assumed for the calculations. The transmission arises from the geometrical measures and the arrangement of the different gear wheels.

The transmission rate is in coherence with the relations of:

- the rotation frequencies,
- the gear wheel diameters,
- the gear wheel cog numbers *,
- the torques.

<u>Note*:</u> as far as the gear wheels have cogs with the same size, which is usually recommended and usually the case.

Thereby the efficiency and the arrangement of the gear wheels have to be taken into consideration, especially for multi-step, planetary or any other complex gear sets. For single-step gear sets auxiliary general calculations are provided on the last *TabPage*. The resulting value can be transferred into the previous *TabPages* due to the selected item in the *ListBox* on the right side of the form.

Both, the values for the transmission rate and the efficiency refer to the complete gear set, which means all compounds (gear wheels etc.) are included in the calculation. The interim values are not displayed!

Regarding the transmission rate there are two possibilities for the handling of this value. One: it can be calculated by the given diameters, if the transmission is deactivated, which means the box on right side form the value is not checked. Two: it can be entered as a predicted value, if the transmission is activated, which means the box on right side form the value is checked. In this case the diameters will be disregarded and the corresponding displays will disappear.

11.1.2. Variables (What are the input and output values? What are their limits?)

diameter

It is the diameter of the corresponding gear wheel. Each gear set is at least transmitting rotation and torque based on the idea of a constant power rate. The transmission is done by using gear wheels with different diameters respectively different tooth numbers with the same tooth size.

The variable type is Input.
The unit is millimeter [mm].
The minimum limit is 0.1.
The maximum limit is 99999.
The replacement value is 200.
The number of digits is 10.

torque

It is the torque of the corresponding gear wheel. Each gear set is at least transmitting rotation and torque based on the idea of a constant power rate. The transmission is done by using gear wheels with different diameters respectively different tooth numbers with the same tooth size.

The variable type is Input or Output.
The unit is Newton by meter [Nm].
The minimum limit is 0.01.
The maximum limit is 9999999999.
The replacement value is 100.
The number of digits is 10.

rotation

It is the rotation frequency of the corresponding gear wheel. Each gear set is at least transmitting rotation and torque based on the idea of a constant power rate. The transmission is done by using gear wheels with different diameters respectively different tooth numbers with the same tooth size.

The variable type is Input or Output.
The unit is one over minute [1 / min].
The minimum limit is 0.01.
The maximum limit is 9999999999.
The replacement value is 100.
The number of digits is 10.

power rate

It is the power rate of the corresponding gear wheel. Each gear set is at least transmitting rotation and torque based on the idea of a constant power rate. The transmission is done by using gear wheels with different diameters respectively different tooth numbers with the same tooth size.

The variable type is Input or Output.
The unit is Watt [W].
The minimum limit is 0.01.
The maximum limit is 9999999999.
The replacement value is 100.
The number of digits is 10.

efficiency

It is the efficiency of the corresponding gear set. Each gear set is at least transmitting rotation and torque based on the idea of a constant power rate. The transmission is done by using gear wheels with different diameters respectively different tooth numbers with the same tooth size. At least there will be frictional losses predominantly at the bearings and where the gear wheels get in contact to each other. That means the output power rate is practically always less that the input power rate. In order to consider this, the efficiency can be entered as a variable.

The variable type is Input.
The unit is percent [%].
The minimum limit is 50.
The maximum limit is 100.
The replacement value is 75.
The number of digits is 10.

transmission

It is the transmission ratio of the corresponding gear set. Each gear set is at least transmitting rotation and torque based on the idea of a constant power rate. The transmission is done by using gear wheels with different diameters respectively different tooth numbers with the same tooth size. The transmission ratio is the relation between the used gear wheel diameters or the relation between the torques or the relation between the rotation frequencies of the used gear wheels.

The variable type is Output.
The variable has no unit [-].
There is no defined minimum limit for output variables.
There is no defined maximum limit for output variables.
There is no defined replacement value for output variables.
There is no defined number of digits for output variables.

In general there are different possibilities to determine the transmission. It can be determined via the relation of the gear wheel diameters, via the relation of the gear wheel torques or via the relation of the gear wheel rotations. Thereby the transmission is defined as follows:

a) The diameter at the output side divided by the diameter at the input side (for one step only).

b) The torque at the output side divided by the torque at the input side.

c) The rotation frequency at the input side divided by the rotation frequency at the output side.

It is obvious that the value for the transmission depends on the side of input and output.

This is why there are always two transmission values displayed. The values are reciprocal to each other. The value with the index "*" is the transmission where the input is assumed to be on the left side and the output is assumed to be on the right side. In case this should be inverse the value without the index "*" is relevant!

11.1.3. Operation (How can it be used? How to proceed?)

Step 1:
Select the variable to be calculated
By clicking on the corresponding *RadioButton* I can choose the variable to be calculated. It is like executing an internal conversion of the equation.

Step 2:
Select the direction of rotation
I can select the direction of rotation, where right is clockwise and left is counter clockwise.

Step 3:
Enter the number of decimal places
I enter the number of decimal places for the output variables.

Step 4:
Consider efficiency
I can select if the efficiency should be considered or not.

Step 5:
Fill the Input-*TextBoxes*
I enter the values for the input variables. I should respect the variable limits and take care that the entered values are numeric.

Step 6:
Calculate result
After I entered the input values I can calculate the result. Before the calculation starts, all the input values are checked by an internal routine. Whenever entered values decrease the corresponding min limits or increase the corresponding max limits or are not numeric there will be a message according to the fault. The values will be corrected automatically by the internal routine.

Step 7:
Check result
After clicking the Calculate-Button I can check the result.

Step 8:
Further actions
After the calculation I can have the following options: Print Data, Erase Data, Program Information, Notes, Save or Restore Values. While printing a new calculation is done automatically. Clicking the Erase-Button will empty all the *TextBoxes* at once.

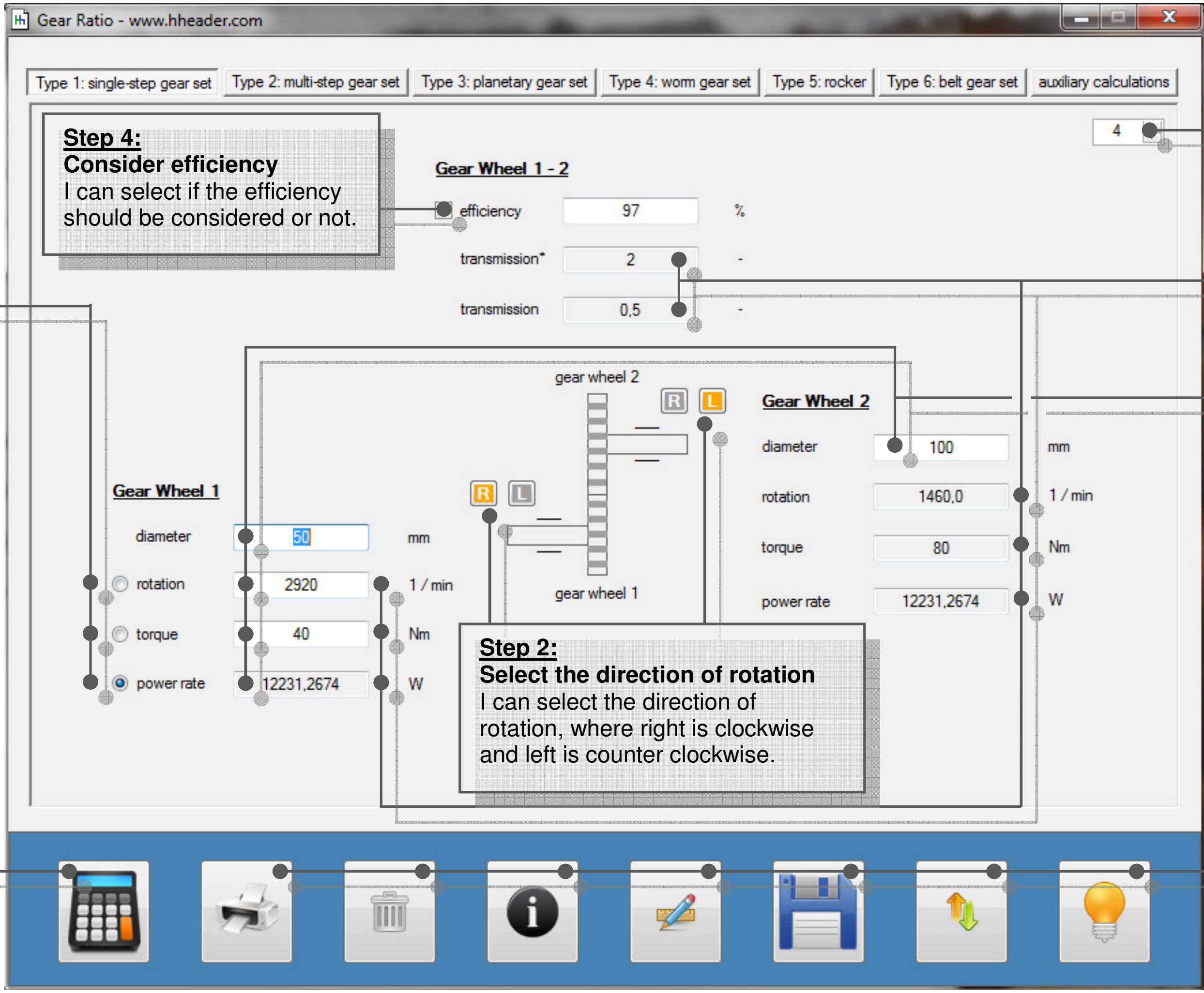


Figure 135: form gear ratio – Type 1: single-step gear set

Step 1:
Select the variable to be calculated
By clicking on the corresponding *RadioButton* I can choose the variable to be calculated. It is like executing an internal conversion of the equation.

Step 2:
Select the direction of rotation
I can select the direction of rotation, where right is clockwise and left is counter clockwise.

Step 3:
Enter the number of decimal places
I enter the number of decimal places for the output variables.

Step 4:
Consider efficiency
I can select if the efficiency should be considered or not.

Step 5:
Fill the Input-*TextBoxes*
I enter the values for the input variables. I should respect the variable limits and take care that the entered values are numeric.

Step 6:
Calculate result
After I entered the input values I can calculate the result. Before the calculation starts, all the input values are checked by an internal routine. Whenever entered values decrease the corresponding min limits or increase the corresponding max limits or are not numeric there will be a message according to the fault. The values will be corrected automatically by the internal routine.

Step 7:
Check result
After clicking the Calculate-Button I can check the result.

Step 8:
Further actions
After the calculation I can have the following options: Print Data, Erase Data, Program Information, Notes, Save or Restore Values. While printing a new calculation is done automatically. Clicking the Erase-Button will empty all the *TextBoxes* at once.

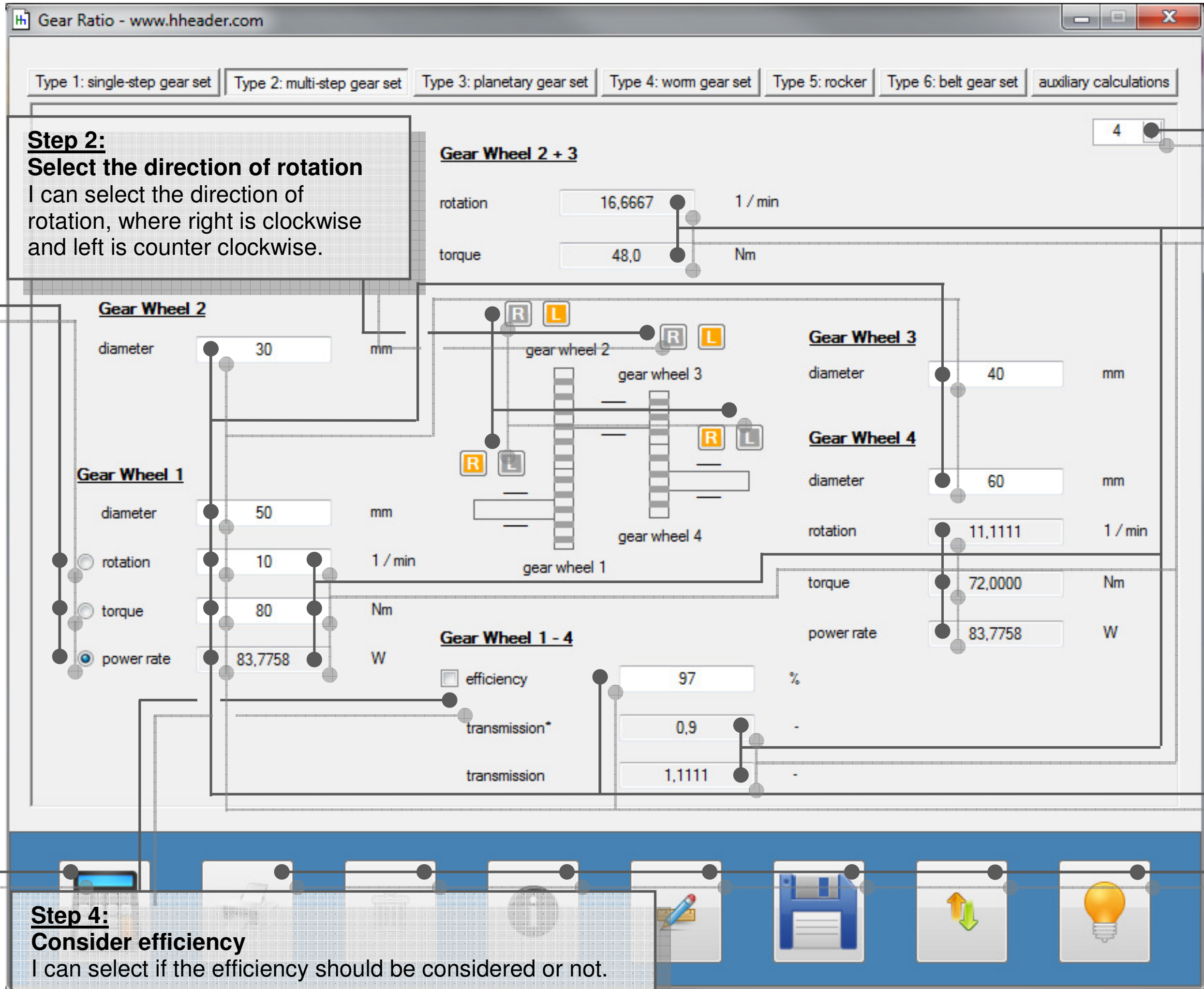
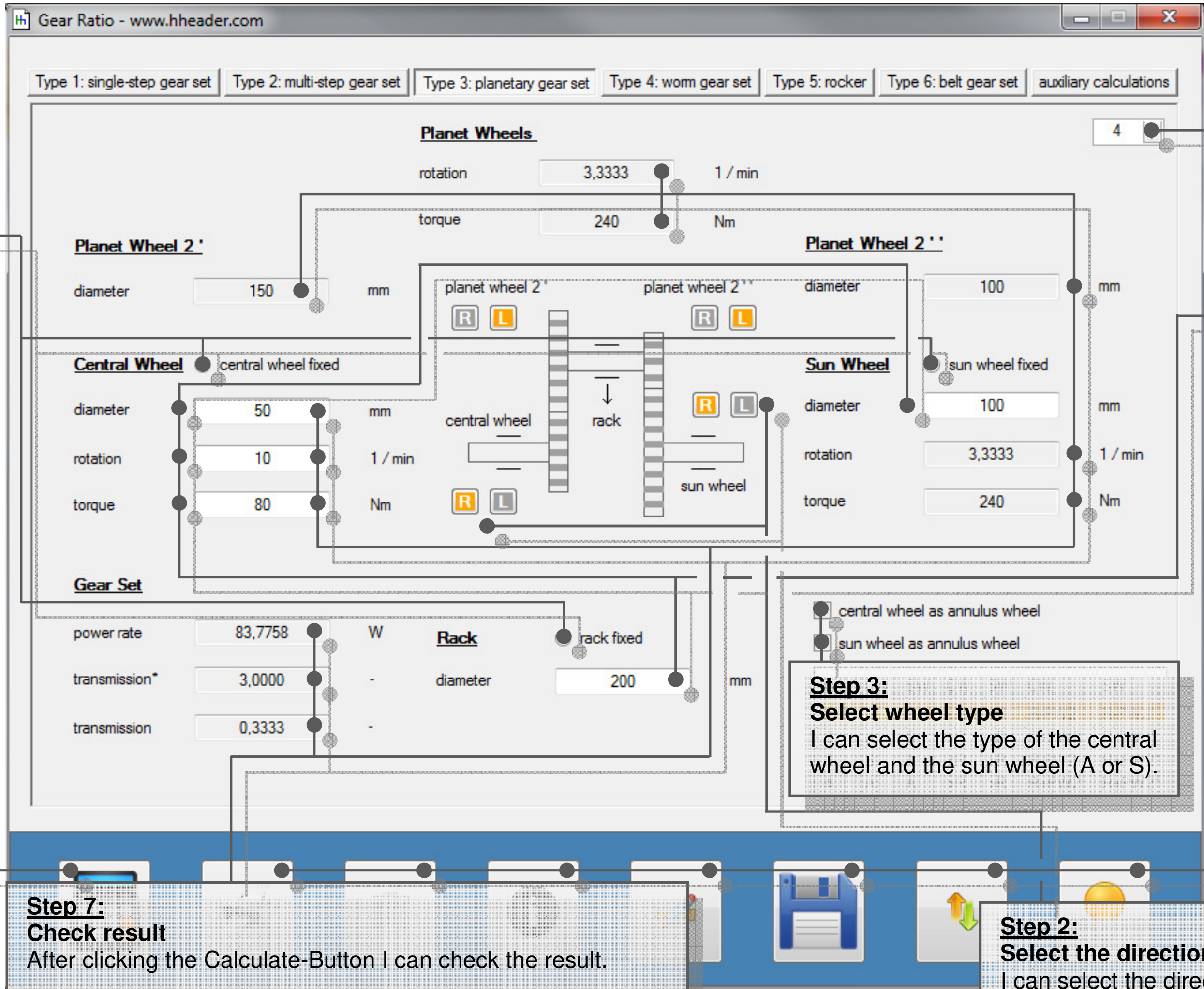


Figure 136: form gear ratio – Type 2: multi-step gear set

Step 1:
Select the fixed wheel
For a defined operation mode one of the compounds has to be fixed. I can select central wheel, rack or sun wheel as to be fixed compound for the provided calculations.

Step 6:
Calculate result
After I entered the input values I can calculate the result. Before the calculation starts, all the input values are checked by an internal routine. Whenever entered values decrease the corresponding min limits or increase the corresponding max limits or are not numeric there will be a message according to the fault. The values will be corrected automatically by the internal routine.



Step 7:
Check result
After clicking the Calculate-Button I can check the result.

Figure 137: form gear ratio – Type 3: planetary gear set

Step 4:
Enter the number of decimal places
I enter the number of decimal places for the output variables.

Step 5:
Fill the Input-*TextBoxes*
I enter the values for the input variables. I should respect the variable limits and take care that the entered values are numeric.

Step 8:
Further actions
After the calculation I can have the following options: Print Data, Erase Data, Program Information, Notes, Save or Restore Values. While printing a new calculation is done automatically. Clicking the Erase-Button will empty all the *TextBoxes* at once.

Step 3:
Select wheel type
I can select the type of the central wheel and the sun wheel (A or S).

Step 2:
Select the direction of rotation
I can select the direction of rotation, where right is clockwise and left is counter clockwise.

Regarding the gear wheel types for the central wheel and the sun wheel there are four different cases provided.

Case 1:

The central wheel is a spur wheel (S).
The sun wheel is a spur wheel (S).
The central wheel diameter is smaller than the rack diameter (CW<R).
The sun wheel diameter is smaller than the rack diameter (SW<R).
The central wheel diameter is equal the rack diameter minus the diameter of the first planet wheel (CW=R-PW2').
The sun wheel diameter is equal the rack diameter minus the diameter of the second planet wheel (CW=R-PW2').

Case 2:

The central wheel is an anulus wheel (A).
The sun wheel is a spur wheel (S).
The central wheel diameter is bigger than the rack diameter (CW>R).
The sun wheel diameter is smaller than the rack diameter (SW<R).
The central wheel diameter is equal the rack diameter plus the diameter of the first planet wheel (CW=R+PW2').
The sun wheel diameter is equal the rack diameter minus the diameter of the second planet wheel (CW=R-PW2'').

Case 3:

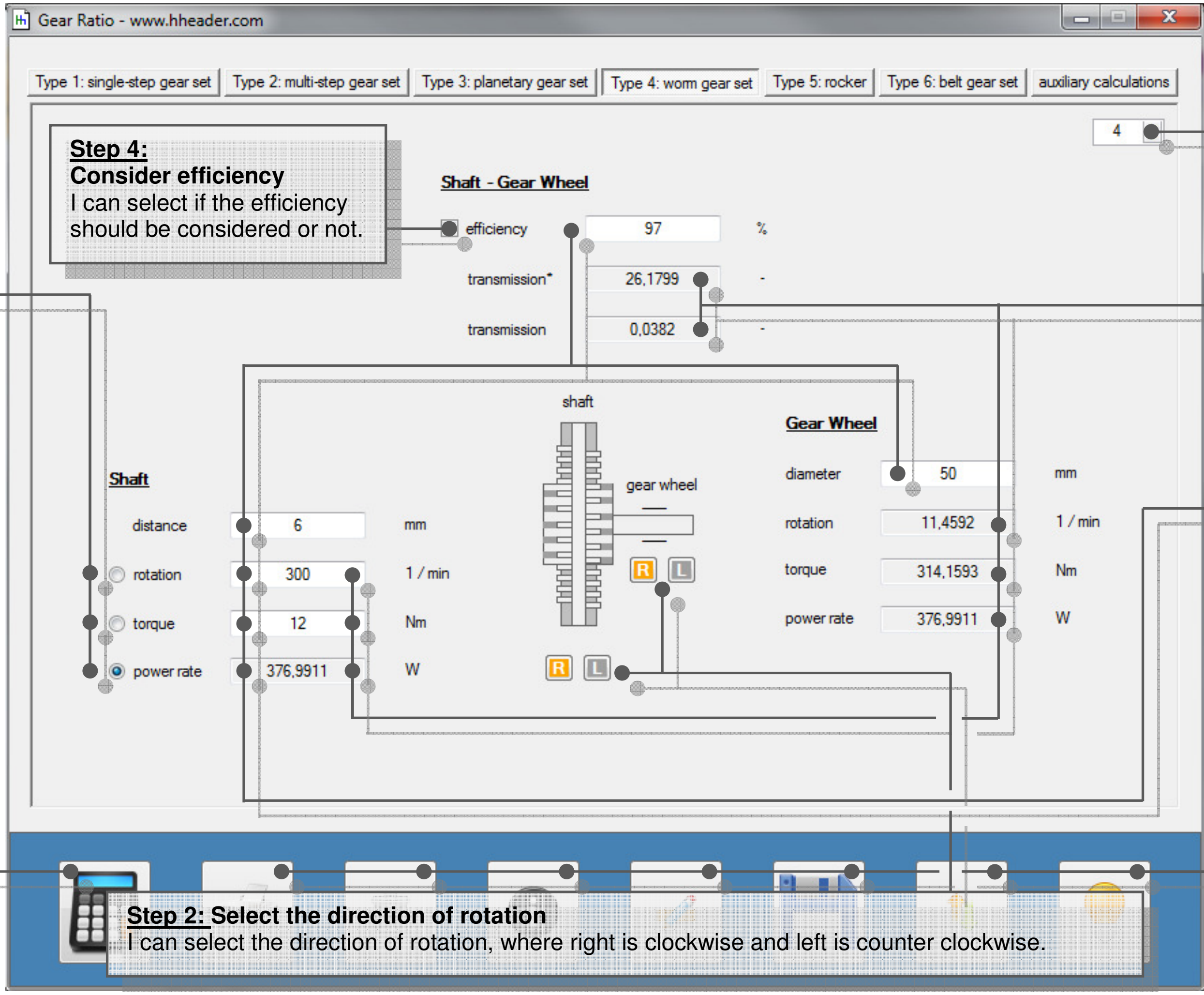
The central wheel is a spur wheel (S).
The sun wheel is a spur wheel (A).
The central wheel diameter is smaller than the rack diameter (CW<R).
The sun wheel diameter is bigger than the rack diameter (SW>R).
The central wheel diameter is equal the rack diameter minus the diameter of the first planet wheel (CW=R-PW2').
The sun wheel diameter is equal the rack diameter plus the diameter of the second planet wheel (CW=R+PW2'').

Case 4:

The central wheel is a spur wheel (A).
The sun wheel is a spur wheel (A).
The central wheel diameter is bigger than the rack diameter (CW>R).
The sun wheel diameter is bigger than the rack diameter (SW>R).
The central wheel diameter is equal the rack diameter plus the diameter of the first planet wheel (CW=R+PW2').
The sun wheel diameter is equal the rack diameter plus the diameter of the second planet wheel (CW=R+PW2').

Step 1:
Select the variable to be calculated
By clicking on the corresponding *RadioButton* I can choose the variable to be calculated. It is like executing an internal conversion of the equation.

Step 6:
Calculate result
After I entered the input values I can calculate the result. Before the calculation starts, all the input values are checked by an internal routine. Whenever entered values decrease the corresponding min limits or increase the corresponding max limits or are not numeric there will be a message according to the fault. The values will be corrected automatically by the internal routine.



Step 4:
Consider efficiency
I can select if the efficiency should be considered or not.

Step 2: Select the direction of rotation
I can select the direction of rotation, where right is clockwise and left is counter clockwise.

Figure 138: form gear ratio – Type 4: worm gear set

Step 3:
Enter the number of decimal places
I enter the number of decimal places for the output variables.

Step 7:
Check result
After clicking the Calculate-Button I can check the result.

Step 5:
Fill the Input-*TextBoxes*
I enter the values for the input variables. I should respect the variable limits and take care that the entered values are numeric.

Step 8:
Further actions
After the calculation I can have the following options: Print Data, Erase Data, Program Information, Notes, Save or Restore Values. While printing a new calculation is done automatically. Clicking the Erase-Button will empty all the *TextBoxes* at once.

Step 1:
Select the variable to be calculated
By clicking on the corresponding *RadioButton* I can choose the variable to be calculated. It is like executing an internal conversion of the equation.

Step 4:
Calculate result
After I entered the input values I can calculate the result. Before the calculation starts, all the input values are checked by an internal routine. Whenever entered values decrease the corresponding min limits or increase the corresponding max limits or are not numeric there will be a message according to the fault. The values will be corrected automatically by the internal routine.

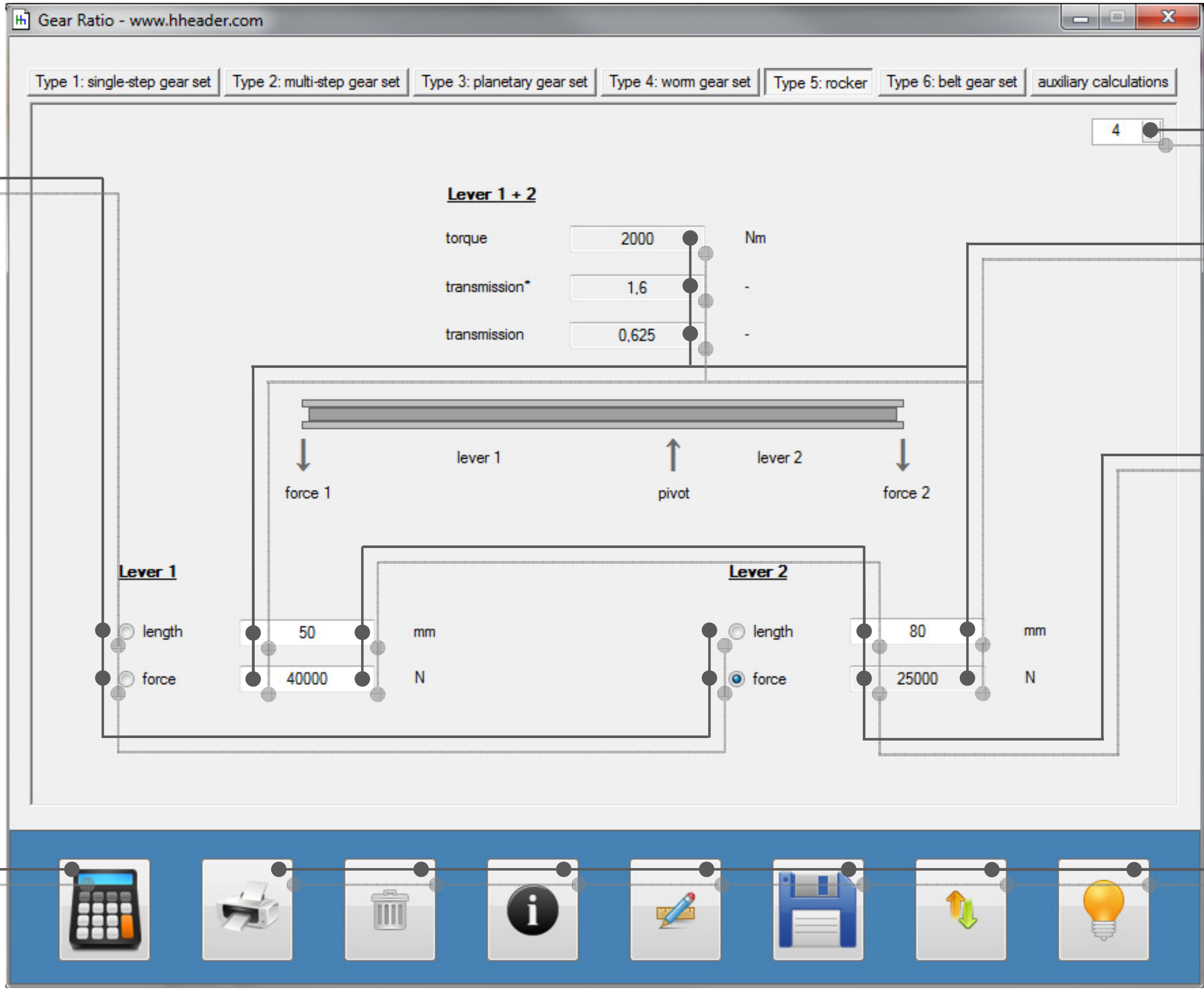


Figure 139: form gear ratio – Type 5: rocker

Step 2:
Enter the number of decimal places
I enter the number of decimal places for the output variables.

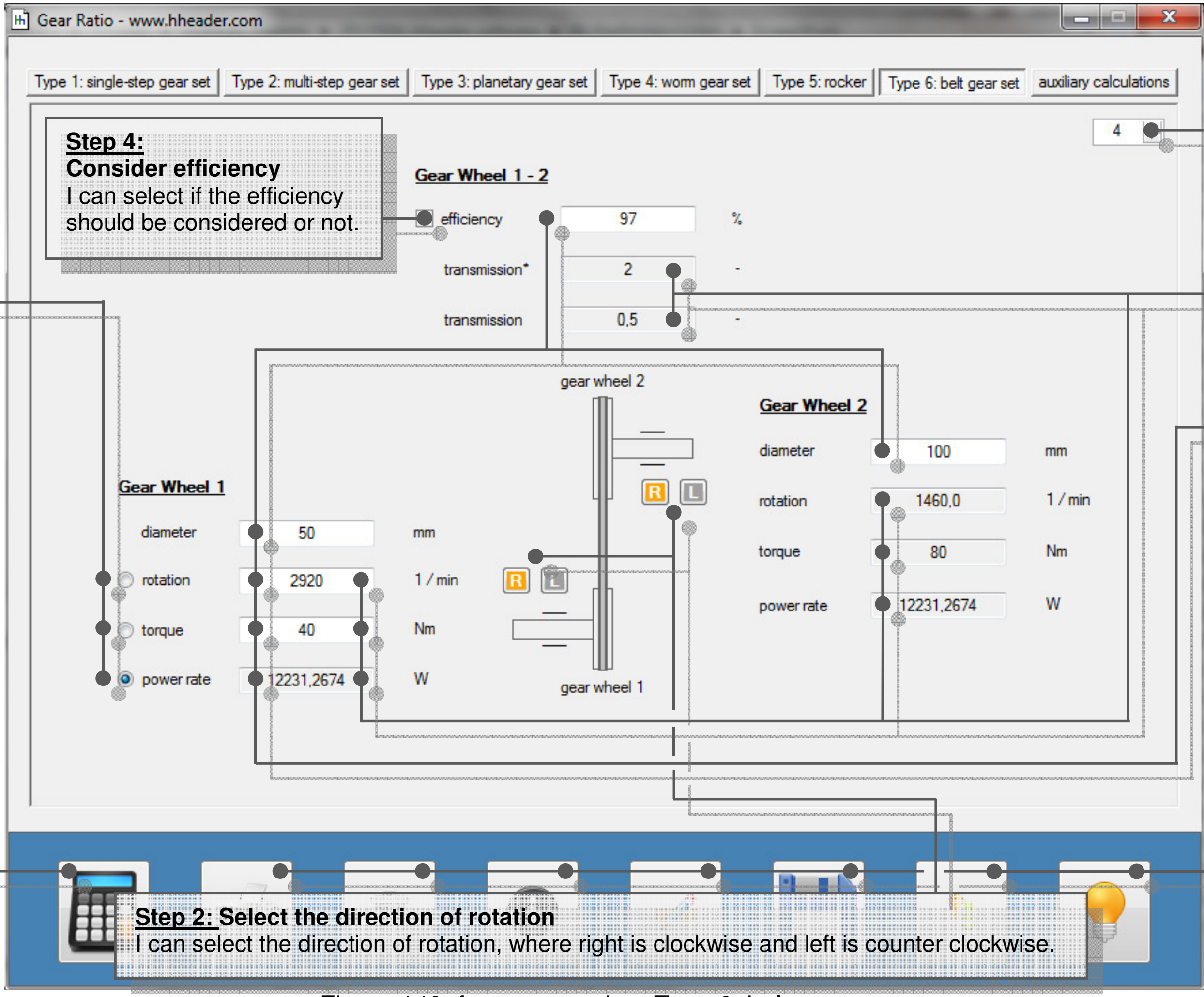
Step 5:
Check result
After clicking the Calculate-Button I can check the result.

Step 3:
Fill the Input-*TextBoxes*
I enter the values for the input variables. I should respect the variable limits and take care that the entered values are numeric.

Step 6:
Further actions
After the calculation I can have the following options: Print Data, Erase Data, Program Information, Notes, Save or Restore Values. While printing a new calculation is done automatically. Clicking the Erase-Button will empty all the *TextBoxes* at once.

Step 1:
Select the variable to be calculated
By clicking on the corresponding *RadioButton* I can choose the variable to be calculated. It is like executing an internal conversion of the equation.

Step 6:
Calculate result
After I entered the input values I can calculate the result. Before the calculation starts, all the input values are checked by an internal routine. Whenever entered values decrease the corresponding min limits or increase the corresponding max limits or are not numeric there will be a message according to the fault. The values will be corrected automatically by the internal routine.



Step 4:
Consider efficiency
I can select if the efficiency should be considered or not.

Step 2: Select the direction of rotation
I can select the direction of rotation, where right is clockwise and left is counter clockwise.

Figure 140: form gear ratio – Type 6: belt gear set

Step 3:
Enter the number of decimal places
I enter the number of decimal places for the output variables.

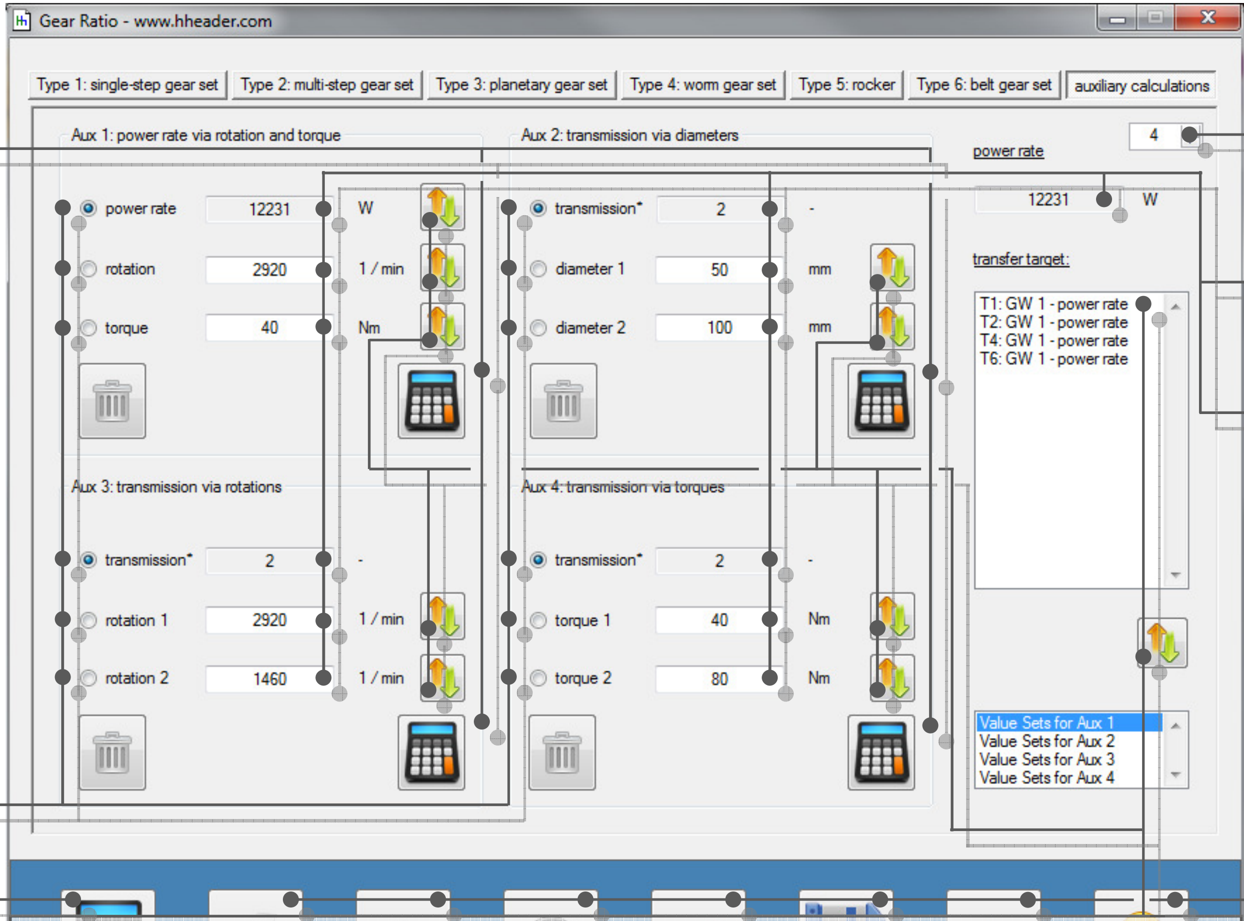
Step 7:
Check result
After clicking the Calculate-Button I can check the result.

Step 5:
Fill the Input-*TextBoxes*
I enter the values for the input variables. I should respect the variable limits and take care that the entered values are numeric.

Step 8:
Further actions
After the calculation I can have the following options: Print Data, Erase Data, Program Information, Notes, Save or Restore Values. While printing a new calculation is done automatically. Clicking the Erase-Button will empty all the *TextBoxes* at once.

Step 4:
Calculate result
After I entered the input values I can calculate the result. Before the calculation starts, all the input values are checked by an internal routine. Whenever entered values decrease the corresponding min limits or increase the corresponding max limits or are not numeric there will be a message according to the fault. The values will be corrected automatically by the internal routine.

Step 1:
Select the variable to be calculated
By clicking on the corresponding *RadioButton* I can choose the variable to be calculated. It is like executing an internal conversion of the equation.



Step 6: (option) Transfer values
Single values can be transferred into a separate TextBox first. At the same time a choice of targets is generated. Further on a transfer target can be selected and the value can be transferred into other TabPages.

Figure 141: form gear ratio – auxiliary calculations

Step 2:
Enter the number of decimal places
I enter the number of decimal places for the output variables.

Step 5:
Check result
After clicking the Calculate-Button I can check the result.

Step 3:
Fill the Input-*TextBoxes*
I enter the values for the input variables. I should respect the variable limits and take care that the entered values are numeric.

Step 7:
Further actions
After the calculation I can have the following options: Print Data, Erase Data, Program Information, Notes, Save or Restore Values. While printing a new calculation is done automatically. Clicking the Erase-Button will empty all the *TextBoxes* at once.

11.2. Stress Analysis

11.2.1. Purpose (What can it be used for? What can it not be used for?)

The program is part of category 6 – mechanics. Supports, beams, clamps or any other imaginable construction or mounting are exposed to different kinds of mechanical stressing. It can be expected that in practice very rarely or even never only one of the kinds occurs. The question is which kinds are significant and which are insignificant. In case if more than one kind of stressing is significant, they have to be brought into focus one by one. The typical kinds of mechanical stressing are:

- tension,
- compression,
- shearing,
- buckling,
- bending,
- torsion.

For these calculations a safety factor is considered. It means at least that the cross section of the material is by the safety factor bigger. This is based on the values that result for a system where the maximum allowed yield stress occurs. Beside this the effective load case is regarded. There are three different types defined:

eff. load case I: static	The effective load is static. That means a defined force or a number of forces are stressing the system continuously with constant values from even directions.
eff. load case II: cycling	The effective load is dynamic and cycling. That means a defined force or a number of forces are stressing the system discontinuously. The force values vary from even directions.
eff. load case III: alternating	The effective load is dynamic and alternating. That means a defined force or a number of forces are stressing the system discontinuously. The force values vary from opposite directions.

The program provides calculations regarding the above mentioned kinds of mechanical stress. Further calculations regarding the elongation of materials are included. Thereby the elongation of materials due to force and temperature are considered. Regarding the elongation calculations the safety factor and the effective load case are disregarded.

For the subprograms (except the elongation by temperature) an equal mass can be entered as an input variable or is calculated as an output variable. This variable is the mass which causes the same stress as the force value. The mass is independent from the location. The resulting force is the product of the mass and the gravity at the position of the construction. For earth a gravity of 9.81 m / s² can be assumed. For the gravity a selection of locations is provided.

Tension:

Tension is the kind of mechanical stress that occurs according to a force that is pulling the material. The specified yield stress is equal to the force over the area under consideration of the safety factor and the effective load case.

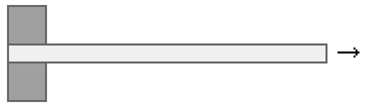


Figure 142: sketch stress analysis - tension

Compression:

Compression is the kind of mechanical stress that occurs according to a force that is pressing the material. The specified yield stress is equal to the force over the area under consideration of the safety factor and the effective load case.

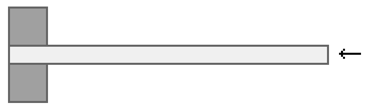


Figure 143: sketch stress analysis - compression

Shearing:

Shearing is the kind of mechanical stress that occurs according to forces that affect the material lateral in order to shear-off. The specified yield stress is equal to the force over the area under consideration of the safety factor and the effective load case. In addition to this the specified yield stress is multiplied by a factor of 0.8, so that the calculation is carried out with a by 20% decreased yield stress.

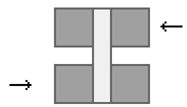
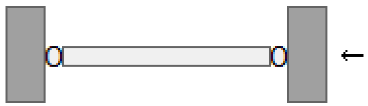


Figure 144: sketch stress analysis - shearing

Buckling:

Buckling is the kind of mechanical stress that occurs according to a force that is pressing a profile bar from the front edge. The force, the elasticity, the moment of inertia and the length of the material are the relevant variables for the calculations. Beside this a safety factor and the effective load case are taken into consideration. The moment of inertia can be calculated on the last *TabPage*. Therefore a profile has to be selected and the measures have to be entered accordingly. After determining the moment of inertia, the value can be transferred into the *TabPage* with the buckling calculations by the corresponding transfer-button.

According to Leonard Euler, there are four different cases considered for the buckling calculations. They are divided up into different kinds of fixing for a profile bar. These are:

Case A: one side tight fixed, one side loose	
Case B: both sides coupled	

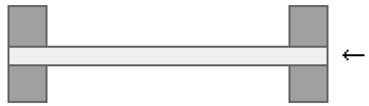
Case C: one side tight fixed, one side coupled	
Case D: both sides tight fixed	

Figure 145: sketches stress analysis – load cases buckling

The case to be regarded for the calculation can be selected via a corresponding *ComboBox*. According to the selection the required coefficients are used automatically for the internal equations.

<u>Modulus of elasticity:</u> if solid objects are applied by forces or pressures, they will be deformed. Unless the forces are not too high the behavior is elastic. The modulus of elasticity defines it for different materials.

Bending:

Bending is the kind of mechanical stress that occurs according to a force that is pressing a profile bar from the top side. Thereby the stress can occur either as a point load or a line load. The force, the yield stress, the axial section modulus and the lever length are the relevant variables for the calculations. Beside this a safety factor and the effective load case are taken into consideration. The axial section modulus can be calculated on the last *TabPage*. Therefore a profile has to be selected and the measures have to be entered accordingly. After determining the axial section modulus, the value can be transferred into the *TabPage* with the bending calculations by the corresponding transfer-button.

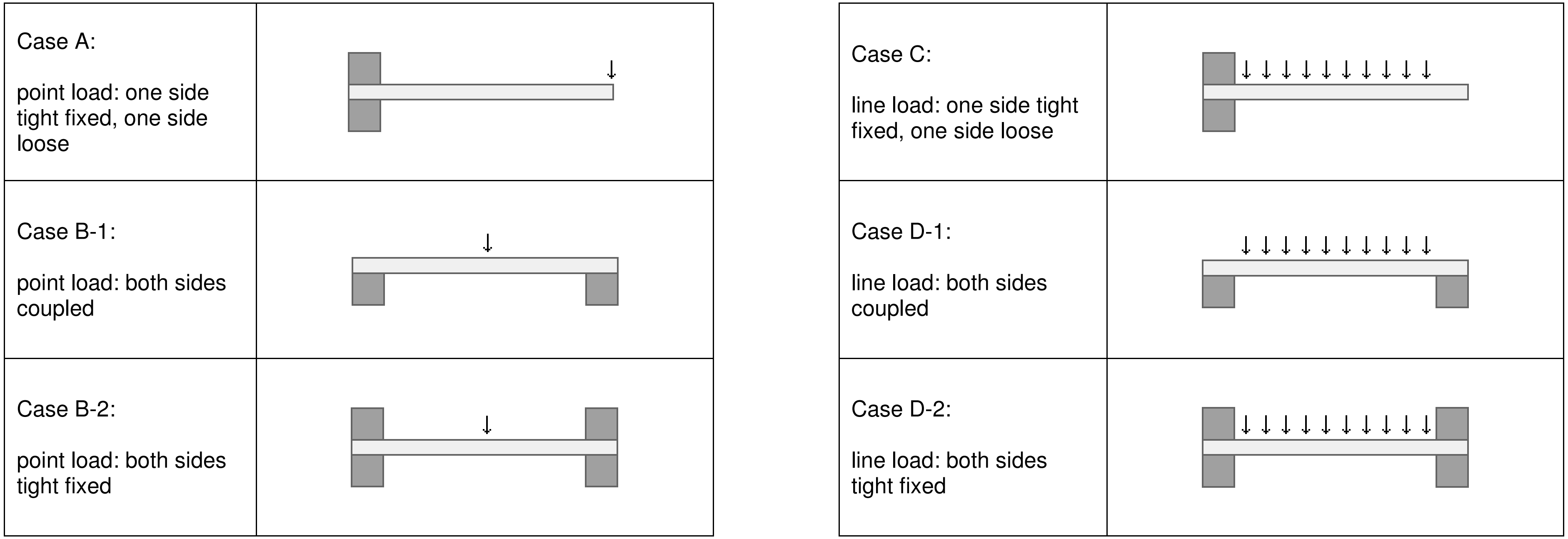


Figure 146: sketches stress analysis – load cases bending

The case to be regarded for the calculation can be selected via a corresponding *ComboBox*. According to selection the required coefficients are used automatically for the internal equations.

Torsion:

Torsion is the kind of mechanical stress that occurs according to a force that is pulling or pushing at the edge of a lever that is arranged in an angle of 90 degree related to a pivot point. The torque results from the force by the lever length. These values, the yield stress and the polar section modulus are the relevant variables for the calculations. Beside this a safety factor and the effective load case are taken into consideration. The polar section modulus can be calculated on the last *TabPage*. Therefore a profile has to be selected and the measures have to be entered accordingly. After determining the polar section modulus, the value can be transferred into the *TabPage* with the bending calculations by the corresponding transfer-button. **Empirical determined torsion section moduli can differ from the calculated polar section modulus – a proper and generous safety factor has to be considered!**

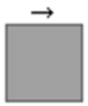


Figure 147: sketch stress analysis - torsion

Elongation:

While a material is stressed by tension or compression a change of the length will occur according to the elasticity of the material and the force value. Be aware that compounds of pulling and pushing forces will occur in every mechanically stressed system. This is independently from the kind of stressing. To evaluate this for complex systems it is required to divide up the system into groups of force compounds which have the same direction. Thereby the angle of the stressing force related to the material is relevant. The forces have to be parted into x-, y- and z-compounds regarding the direction axis. Only elongations and the forces with the same direction belong together. If the yield stress is below the ultimate tensile strength (elastic region) the material will turn back to its original dimensions when the force disappears again. If the yield stress is above the ultimate tensile strength (plastic region) the material will be deformed.

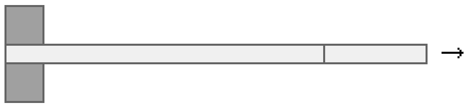


Figure 148: sketch stress analysis - elongation

The elasticity, the force, and the cross section of the material are relevant for the calculations of the elongation, which is the change of length over the original length. Beside this also the value for the restriction is calculated. The force will not only generate a change of the material length, but also a restriction of the material cross section. Regarding this two parameters are important.

<u>Modulus of elasticity:</u> if solid objects are applied by forces or pressures, they will be deformed. Unless the forces are not too high the behavior is elastic. The modulus of elasticity defines it for different materials.

<u>Poisson number:</u> if solid objects are deformed by high forces, the cross section will decrease while there is an elongation. A measure for this behavior is the poisson number. It is defined for different materials.

Temperature:

Increasing or decreasing the ambient temperature will take influence on the size of materials. A measure for this behavior is the temperature coefficient alpha. It is at least the relation of the elongation as the delta length over the total original length per Kelvin. Thereby the original length is assumed to be measured at a temperature of 20°C which is equal 293.16 Kelvin. The program provides calculations regarding this subject. It is useful for the evaluation of constructions and mountings which are exposed to high temperature changes respectively temperature cycling. The relevant variables are the original length or width at 20°C, the ambient temperature that should be considered and the temperature coefficient alpha. The unit of the temperature coefficient is 1 over a million (1 / 10^6 or 10^-6) per Kelvin [1 / (10^6 K)]. The results are the delta length (elongation), the total length at the given temperature and the relation delta length over the total original length.

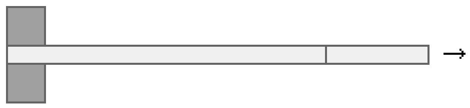


Figure 149: sketch stress analysis - temperature

Moments of inertia and section modulus:

On the last *TabPage* of the form calculations for the moment of inertia, the section modulus and the cross section of different profiles are provided. The axial moment of inertia is required for the buckling calculations, the axial section modulus is required for the bending calculations and the polar section modulus can be used for the torsion calculations. By the way: beside this the moment of inertia and the section modulus are relevant for many other different calculations. The above mentioned values are depending on the profile type and the measures. The program provides a selection of twelve established profile types. These are:

- circle profile,
- circular ring,
- rectangle profile,
- hollow rectangle profile,
- C – profile,
- I – profile,
- L – profile,
- T – profile,
- X – profile,
- Z – profile,
- hexagon profile,
- octagon profile.

The following values are calculated depending on the selected profile type and the entered measures. It has to be considered that the directions for the y-axis and the x-axis are predefined in the program as displayed in the form.

Moments of inertia:

- Jx (moment of inertia for the x-axis),
- Jy (moment of inertia for the y-axis),
- Jp (polar moment of inertia),

The unit for the moment of inertia is millimeter to the power of four [mm^4].

Axial and polar section modulus:

- Wax (axial section modulus for the x-axis),
- Way (axial section modulus for the y-axis),
- Wp (polar section modulus).

The unit for the axial and polar section modulus is millimeter to the power of three [mm^3].

Beside the value on the left, there are transfer buttons provided. The transfer targets which are corresponding to the single buttons are shown below:

Transfer-*Button*	**Target *TabPage***	**Target *TextBox***
Jx	Buckling	Moment of inertia
Jy	Buckling	Moment of inertia
Wax	Bending	Axial section modulus
Way	Bending	Axial section modulus
Wp	Torsion	Polar section modulus
Cross section	Tension	Cross section
Cross section	Compression	Cross section
Cross section	Shearing	Cross section
Cross section	Elongation	Cross section

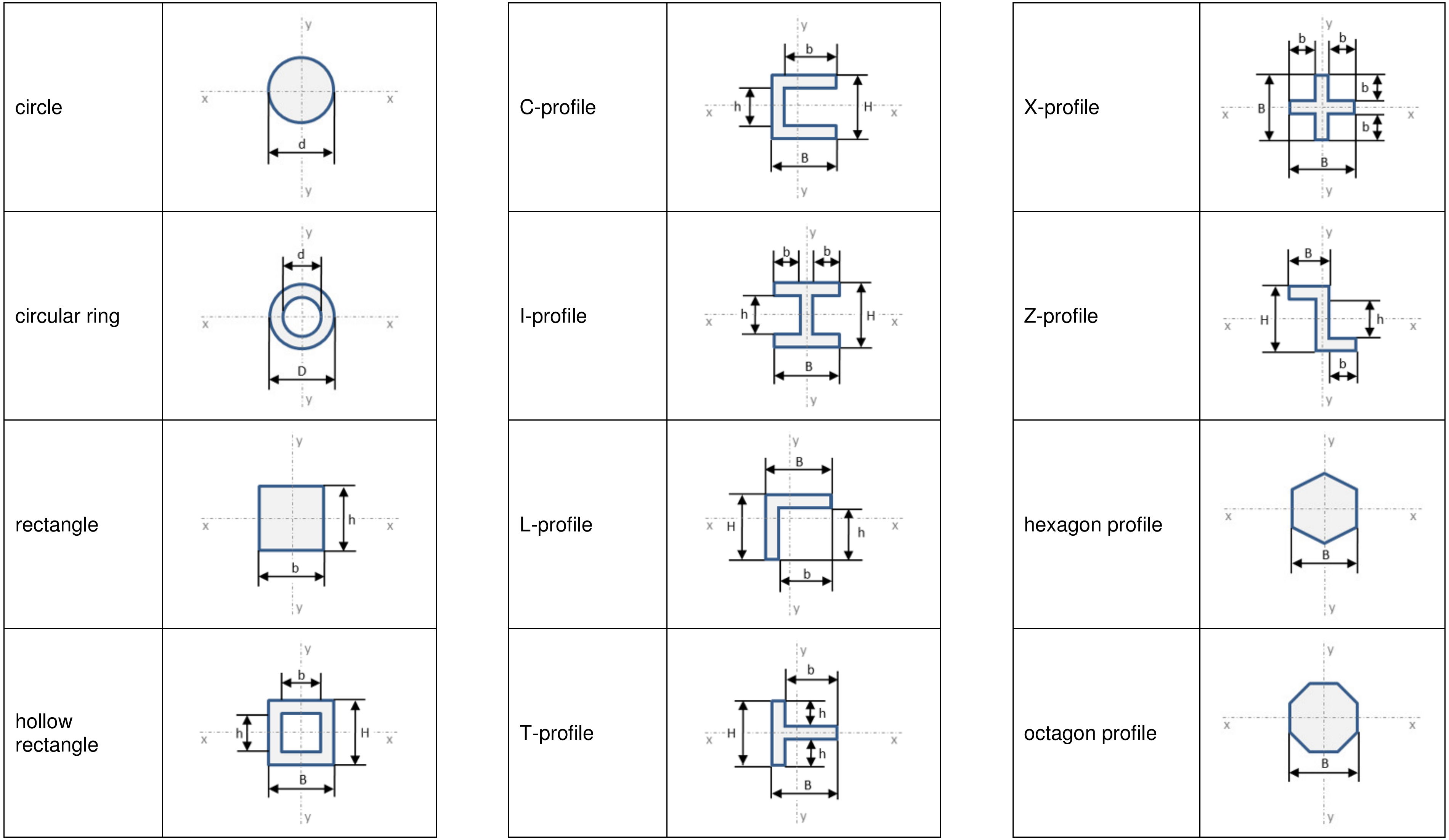


Figure 150: sketches stress analysis – moments of inertia

Beside the axial and polar moments of inertia and the axial and polar section modulus also the cross section of the selected profile is calculated. The cross section for a single profile is multiplied by the number of support points. In case if a construction has a certain amount of support points which have the selected profile shape, the total cross section that is relevant for the static criteria is calculated in advance. This value can be transferred into the previous *TabPages* (tension, compression, shearing and elongation) as an input variable for the area respectively the cross section by clicking the transfer-button.

For the above mentioned subprograms (except the elongation by temperature) an equal mass can be entered as an input variable or is calculated as an output variable. This variable is the mass which causes the same stress as the force value. The mass is independent from the location. The resulting force is the product of the mass and the gravity at the location of the construction. For earth a gravity of 9.81 m / s² can be assumed. For the gravity a selection of locations is provided.

Gravity by location:

- Mercury (g= 3.7 m/s²),
- Venus (g= 8.87 m/s²),
- Earth (g= 9.80665 m/s²),
- Moon (g= 1.62 m/s²),
- Mars (g= 3.71 m/s²),
- Jupiter (g= 24.79 m/s²),
- Amalthea (g= 0.02 m/s²),
- Io (g= 1.81 m/s²),
- Europa (g= 1.32 m/s²),
- Ganymed (g= 1.42 m/s²),
- Kallisto (g= 1.32 m/s²),
- Himalia (g= 0.062 m/s²),
- Saturn (g= 10.44 m/s²),
- Titan (g= 1.35 m/s²),
- Rhea (g= 0.26 m/s²),
- Japetus (g= 0.2553 m/s²),
- Dione (g= 0.22 m/s²),
- Tethys (g= 0.147 m/s²),
- Enceladus (g= 0.114 m/s²),
- Mimas (g= 0.0636 m/s²),
- Hyperion (g= 0.041 m/s²),
- Uranus (g= 8.87 m/s²),
- Titania (g= 0.378 m/s²),
- Oberon (g= 0.346 m/s²),
- Umbriel (g= 0.23 m/s²),
- Ariel (g= 0.27 m/s²),
- Miranda (g= 0.079 m/s²),
- Puck (g= 0.029 m/s²),
- Sycorax (g= 0.04 m/s²),
- Portia (g= 0.0246 m/s²),
- Neptune (g= 11.15 m/s²),
- Triton (g= 0.779 m/s²),
- Proteus (g= 0.075 m/s²),
- Nereide (g= 0.07 m/s²),
- Larissa (g= 0.0355 m/s²),
- Galatea (g= 0.02045 m/s²),
- Despina (g= 0.027 m/s²),
- Thalassa (g= 0.015 m/s²),
- Naiad (g= 0.012 m/s²),
- Pluto (g= 0.62 m/s²).

11.2.2. Variables (What are the input and output values? What are their limits?)

eff. load case

It is the effective load case for the stress of the material. In general three different load cases are possible. Load case one (static) is for a permanently constant force in one direction. Load case two (cycling) is a dynamic stress in one direction, where the value of the force is changing frequently. Load case three (alternating) is a dynamic stress in two directions, where the value of the force is changing frequently.

The variable type is Input.
The variable has no unit [-].
The minimum limit is 0.01.
The maximum limit is 0.99.
The replacement value is 0.13.
The number of digits is 10.

cross section

It is cross section of the construction or profile at the critical position that is focus for the calculations.

The variable type is Input or Output.
The unit is millimeter square [mm²].
The minimum limit is 0.0001.
The maximum limit is 9999999999.
The replacement value is 10.
The number of digits is 10.

spec. yield stress

It is the specified yield stress that can be assumed for the construction that is focus for the calculations. The yield stress is at least a measure for the force that can occur in relation to a defined area without causing plastic deformations for the material.

The variable type is Input or Output.
The unit is Newton per millimeter square [N / mm²].
The minimum limit is 0.1.
The maximum limit is 9999.
The replacement value is 360.
The number of digits is 10.

factor for safety

It is a factor for safety that should be considered in general for such calculations. The factor depends on the danger that is caused by a damaged construction. In every case the factor should be greater than 1. For basic consoles and support constructions a factor of 2 or 3 can be assumed as proper. In some cases safety factors greater than 10 are also possible.

The variable type is Input.
The variable has no unit [-].
The minimum limit is 1.
The maximum limit is 9999.
The replacement value is 3.
The number of digits is 10.

force

It is the force that is basis for the stress of the construction that is focus for the calculations.

The variable type is Input or Output.
The unit is Newton [N].
The minimum limit is 0.0001.
The maximum limit is 9999999999.
The replacement value is 10.
The number of digits is 10.

equal mass

It is the mass which causes the same stress as the force. The mass is independent from the location. The resulting force is the product of the mass and the gravity at the location of the construction. For earth a gravity of 9.81 m / s² can be assumed. For the gravity a selection of locations is provided.

The variable type is Input or Output.
The unit is kilogram [kg].
The minimum limit is 0.0001.
The maximum limit is 9999999999.
The replacement value is 10.
The number of digits is 10.

elasticity

It is the elasticity of the material that is used for the construction. If solid objects are applied by forces or pressures, they will be deformed. Unless the forces are not too high the behavior is elastic. The modulus of elasticity defines it for different materials. The base unit is N/m² or Pa.

The variable type is Input.
The unit is kilo-Newton per millimeter square [kN / mm²].
The minimum limit is 0.1.
The maximum limit is 9999.
The replacement value is 210.
The number of digits is 10.

moment of inertia

It is the moment of inertia for the profile that is focus for the calculations. The moment of inertia has to be determined for each profile with its typical measures. A selection of standard profiles is provided in this program. The moment of inertia can be calculated by the given measures.

The variable type is Input.
The unit is millimeter to the power of four [mm^4].
The minimum limit is 0.0001.
The maximum limit is 9999999999.
The replacement value is 10.
The number of digits is 10.

length

It is the length of the profile or construction part that is focus for the calculations.

The variable type is Input or Output.
The unit is millimeter [mm].
The minimum limit is 0.0001.
The maximum limit is 9999999999.
The replacement value is 10.
The number of digits is 10.

torque

It is the torque that stresses the profile or construction part that is focus for the calculations.

The variable type is Input or Output.
The unit is Newton by meter [Nm].
The minimum limit is 0.0001.
The maximum limit is 9999999999.
The replacement value is 10.
The number of digits is 10.

axial section modulus

It is the axial section modulus for the profile that is focus for the calculations. The axial section modulus has to be determined for each profile with its typical measures. A selection of standard profiles is provided in this program. The axial section modulus can be calculated by the given measures.

The variable type is Input.
The unit is millimeter cube [mm^3].
The minimum limit is 0.0001.
The maximum limit is 9999999999.
The replacement value is 10.
The number of digits is 10.

lever length

It is the length of the lever that is focus for the calculations. The lever is arranged in an angle of 90 degree to the force.

The variable type is Input or Output.
The unit is millimeter [mm].
The minimum limit is 0.0001.
The maximum limit is 9999999999.
The replacement value is 10.
The number of digits is 10.

polar section modulus

It is the polar section modulus for the profile that is focus for the calculations. The polar section modulus has to be determined for each profile with its typical measures. A selection of standard profiles is provided in this program. The polar section modulus can be calculated by the given measures.

The variable type is Input.
The unit is millimeter cube [mm^3].
The minimum limit is 0.0001.
The maximum limit is 9999999999.
The replacement value is 10.
The number of digits is 10.

poisson number

It is the poisson number for the material. If solid objects are deformed by high forces, the cross section will decrease while there is an elongation. A measure for this behavior is the poisson number. It is defined for different materials.

The variable type is Input.
The variable has no unit [-].
The minimum limit is 0.01.
The maximum limit is 0.9.
The replacement value is 0.3.
The number of digits is 10.

delta l/L

It is the relation between the differential length which is caused by the force and the base length of the material.

The variable type is Input or Output.
The variable has no unit [-].
The minimum limit is 0.0001.
The maximum limit is 9999999999.
The replacement value is 10.
The number of digits is 10.

delta d/D

It is the relation between the differential diameter which is caused by the force and the base diameter of the material.

The variable type is Input or Output.
The variable has no unit [-].
The minimum limit is 0.0001.
The maximum limit is 9999999999.
The replacement value is 10.
The number of digits is 10.

temperature

It is the actual ambient temperature of the construction that is focus for the calculations. Usually the nominal measures are given at a temperature of 20°C which is equal to 273.16 Kelvin. In case if the temperature increases or decreases, the material will expand or shrink according to its temperature coefficient.

The variable type is Input.
The unit is degree Celsius [°C].
The minimum limit is -50.
The maximum limit is 1750.
The replacement value is 20.
The number of digits is 10.

alpha

It is the temperature coefficient of the construction material that is focus for the calculations. Usually the nominal measures are given at a temperature of 20°C which is equal to 273.16 Kelvin. In case if the temperature increases or decreases, the material will expand or shrink according to its temperature coefficient.

The variable type is Input.
The unit is 10^-6 per Kelvin [10^-6 / K].
The minimum limit is 0.0001.
The maximum limit is 9999999999.
The replacement value is 10.
The number of digits is 10.

length begin

It is the length of the material or profile at the start of the consideration. It means that the material or profile is not stressed by any additional force and the ambient temperature is assumed to be 20°C.

The variable type is Input.
The unit is millimeter [mm].
The minimum limit is 0.0001.
The maximum limit is 9999999999.
The replacement value is 10.
The number of digits is 10.

length delta

It is the differential length of the material or profile between the start and the end of the consideration. It means that the material or profile is stressed by any additional force or the ambient temperature is less or greater that 20°C.

The variable type is Output.
The unit is millimeter [mm].
There is no defined minimum limit for output variables.
There is no defined maximum limit for output variables.
There is no defined replacement value for output variables.
There is no defined number of digits for output variables.

length end

It is the length of the material or profile at the end of the consideration. It means that the material or profile is stressed by any additional force or the ambient temperature is less or greater that 20°C.

The variable type is Output.
The unit is millimeter [mm].
There is no defined minimum limit for output variables.
There is no defined maximum limit for output variables.
There is no defined replacement value for output variables.
There is no defined number of digits for output variables.

ex, ey, ep, sx, sy, sp

These measures are displayed on the last *TabPage* below the profiles. They are the corresponding edge distances, which are measured from the balance point to the outer edge of the profile. Thereby the variables with the "e" included are assumed to be the distances to the left side and the variables with the "s" included are assumed to be the distances to the right side of the balance point. The variables with the “x” included are the distances measured from the x-axis to the edge line of the profile. The variables with the “y” included are the distances measured from the y-axis to the edge line of the profile. The variables with the “p” included are the distances measured from the balance point to the outer edge points of the profile.

The variable type is Output.
The unit is millimeter [mm].
There is no defined minimum limit for output variables.
There is no defined maximum limit for output variables.
There is no defined replacement value for output variables.
There is no defined number of digits for output variables.

Tx, Ty

It is the wall thickness of the material in direction of the corresponding axis, where the x-axis is relevant for Tx and the y-axis is relevant for Ty. Attention: the Ty-value for the hexagon profile is an average value.

The variable type is Output.
The unit is millimeter [mm].
There is no defined minimum limit for output variables.
There is no defined maximum limit for output variables.
There is no defined replacement value for output variables.
There is no defined number of digits for output variables.

11.2.3. Operation (How can it be used? How to proceed?)

Step 2:
Select the variable to be calculated
By clicking on the corresponding *RadioButton* I can choose the variable to be calculated. It is like executing an internal conversion of the equation.

Step 1: (option)
Select a material
I can select the material in order to display the corresponding yield stress. I can transfer the value for the yield stress into the corresponding *TextBox* by clicking the transfer button.

Step 5:
Calculate result
After I entered the input values I can calculate the result. Before the calculation starts, all the input values are checked by an internal routine. Whenever entered values decrease the corresponding min limits or increase the corresponding max limits or are not numeric there will be a message according to the fault. The values will be corrected automatically by the internal routine.

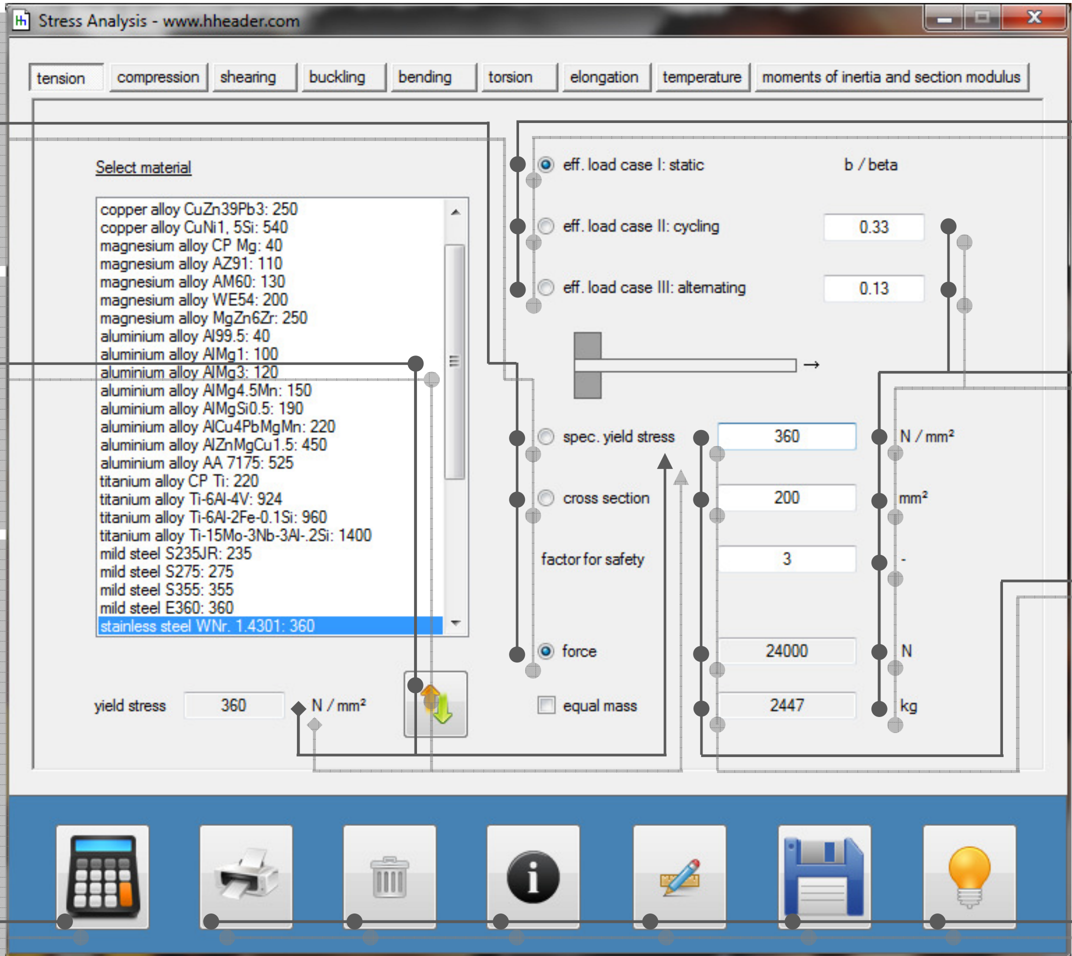


Figure 151: form stress analysis - tension

Step 3:
Select the load case
By clicking on the corresponding *RadioButton* I can choose the effective load case for the calculations. There are three cases provided with corresponding factors.

Step 4:
Fill the Input-*TextBoxes*
I enter the values for the input variables. I should respect the variable limits and take care that the entered values are numeric.

Step 6:
Check result
After clicking the Calculate-Button I can check the result.

Step 7:
Further actions
After the calculation I can have the following options: Print Data, Erase Data, Program Information, Notes, Save or Restore Values. While printing a new calculation is done automatically. Clicking the Erase-Button will empty all the *TextBoxes* at once.

Step 2:
Select the variable to be calculated
By clicking on the corresponding *RadioButton* I can choose the variable to be calculated. It is like executing an internal conversion of the equation.

Step 1: (option)
Select a material
I can select the material in order to display the corresponding yield stress. I can transfer the value for the yield stress into the corresponding *TextBox* by clicking the transfer button.

Step 5:
Calculate result
After I entered the input values I can calculate the result. Before the calculation starts, all the input values are checked by an internal routine. Whenever entered values decrease the corresponding min limits or increase the corresponding max limits or are not numeric there will be a message according to the fault. The values will be corrected automatically by the internal routine.

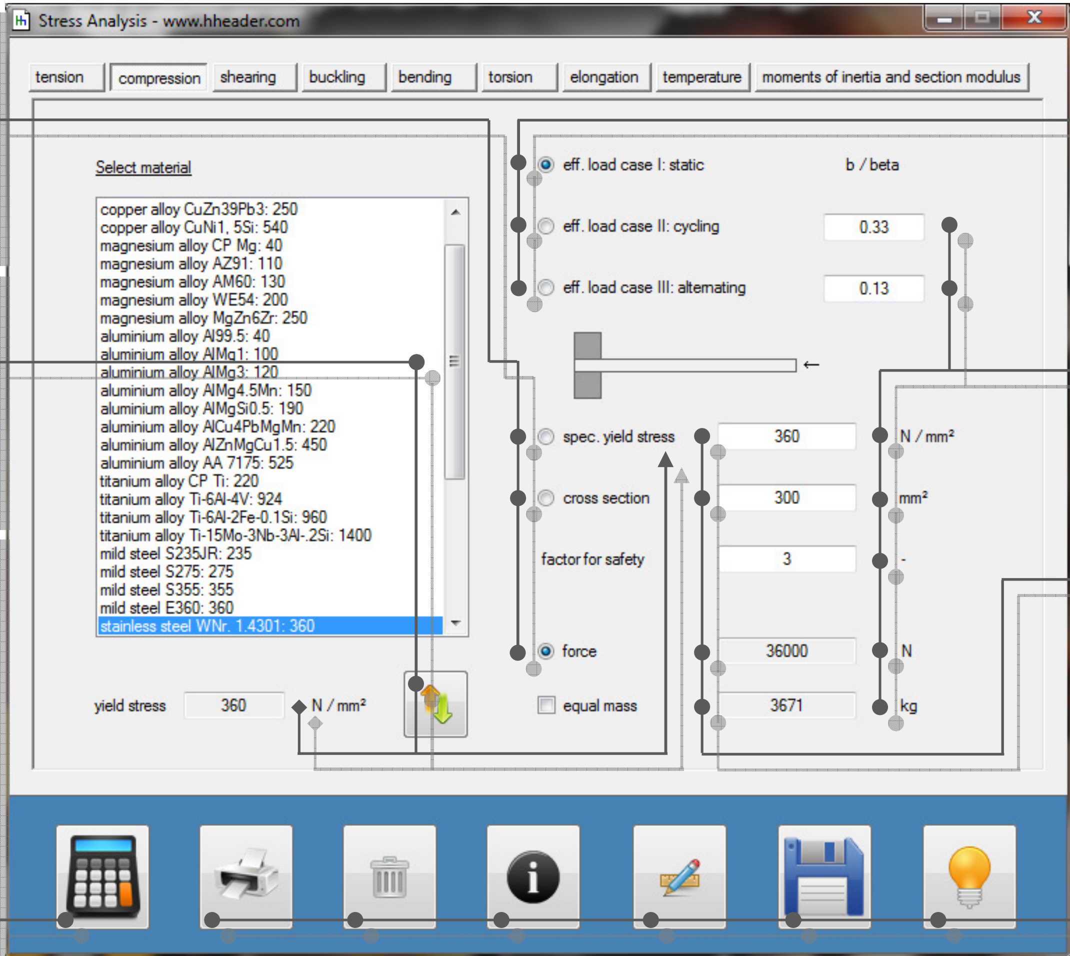


Figure 152: form stress analysis - compression

Step 3:
Select the load case
By clicking on the corresponding *RadioButton* I can choose the effective load case for the calculations. There are three cases provided with corresponding factors.

Step 4:
Fill the Input-*TextBoxes*
I enter the values for the input variables. I should respect the variable limits and take care that the entered values are numeric.

Step 6:
Check result
After clicking the Calculate-Button I can check the result.

Step 7:
Further actions
After the calculation I can have the following options: Print Data, Erase Data, Program Information, Notes, Save or Restore Values. While printing a new calculation is done automatically. Clicking the Erase-Button will empty all the *TextBoxes* at once.

Step 2:
Select the variable to be calculated
By clicking on the corresponding *RadioButton* I can choose the variable to be calculated. It is like executing an internal conversion of the equation.

Step 1: (option)
Select a material
I can select the material in order to display the corresponding yield stress. I can transfer the value for the yield stress into the corresponding *TextBox* by clicking the transfer button.

Step 5:
Calculate result
After I entered the input values I can calculate the result. Before the calculation starts, all the input values are checked by an internal routine. Whenever entered values decrease the corresponding min limits or increase the corresponding max limits or are not numeric there will be a message according to the fault. The values will be corrected automatically by the internal routine.

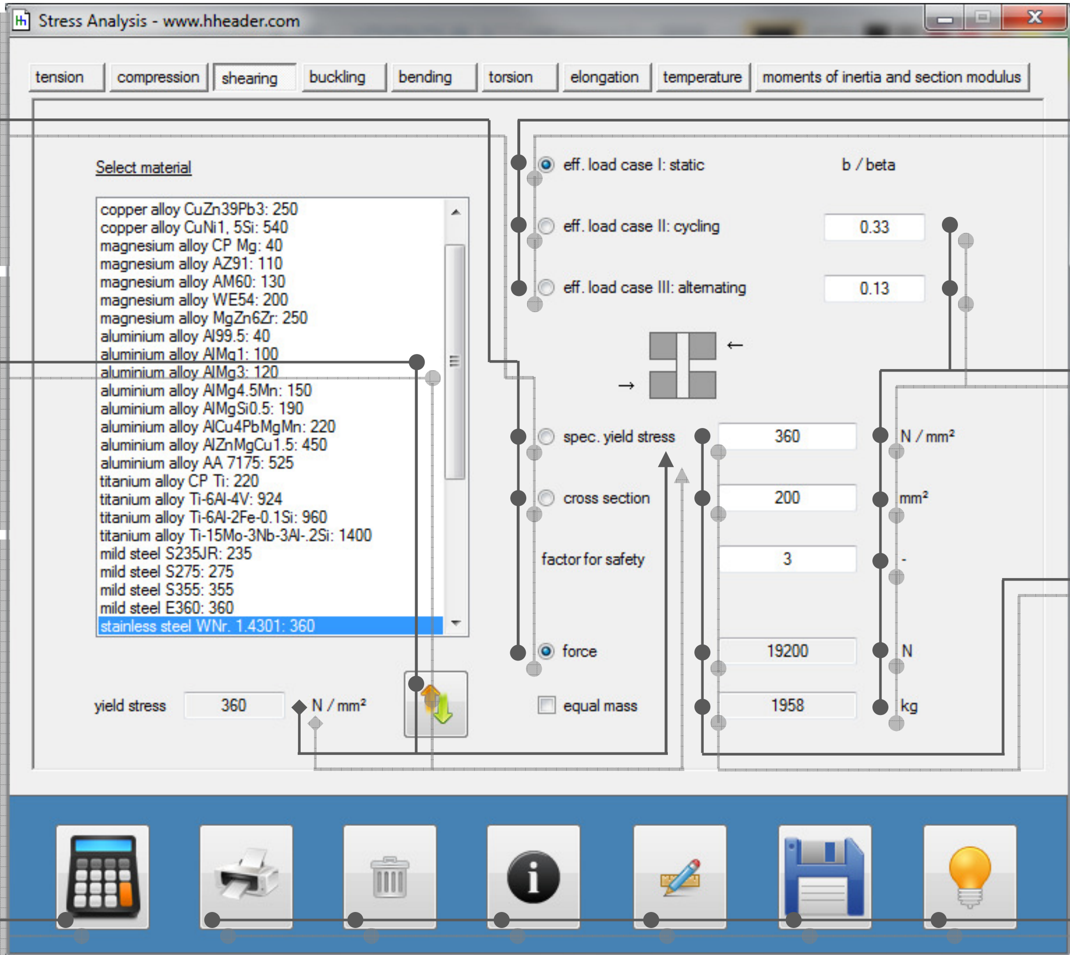


Figure 153: form stress analysis - shearing

Step 3:
Select the load case
By clicking on the corresponding *RadioButton* I can choose the effective load case for the calculations. There are three cases provided with corresponding factors.

Step 4:
Fill the Input-*TextBoxes*
I enter the values for the input variables. I should respect the variable limits and take care that the entered values are numeric.

Step 6:
Check result
After clicking the Calculate-Button I can check the result.

Step 7:
Further actions
After the calculation I can have the following options: Print Data, Erase Data, Program Information, Notes, Save or Restore Values. While printing a new calculation is done automatically. Clicking the Erase-Button will empty all the *TextBoxes* at once.

Step 4:
Select the variable to be calculated
By clicking on the corresponding *RadioButton* I can choose the variable to be calculated. It is like executing an internal conversion of the equation.

Step 1: (option)
Select a material
I can select the material in order to display the corresponding elasticity. I can transfer the value for the elasticity into the corresponding *TextBox* by clicking the transfer button.

Step 2:
Select the fixing type
I can select the fixing type. Four different types are provided.

Step 6:
Calculate result
After I entered the input values I can calculate the result. Before the calculation starts, all the input values are checked by an internal routine. Whenever entered values decrease the corresponding min limits or increase the corresponding max limits or are not numeric there will be a message according to the fault. The values will be corrected automatically by the internal routine.

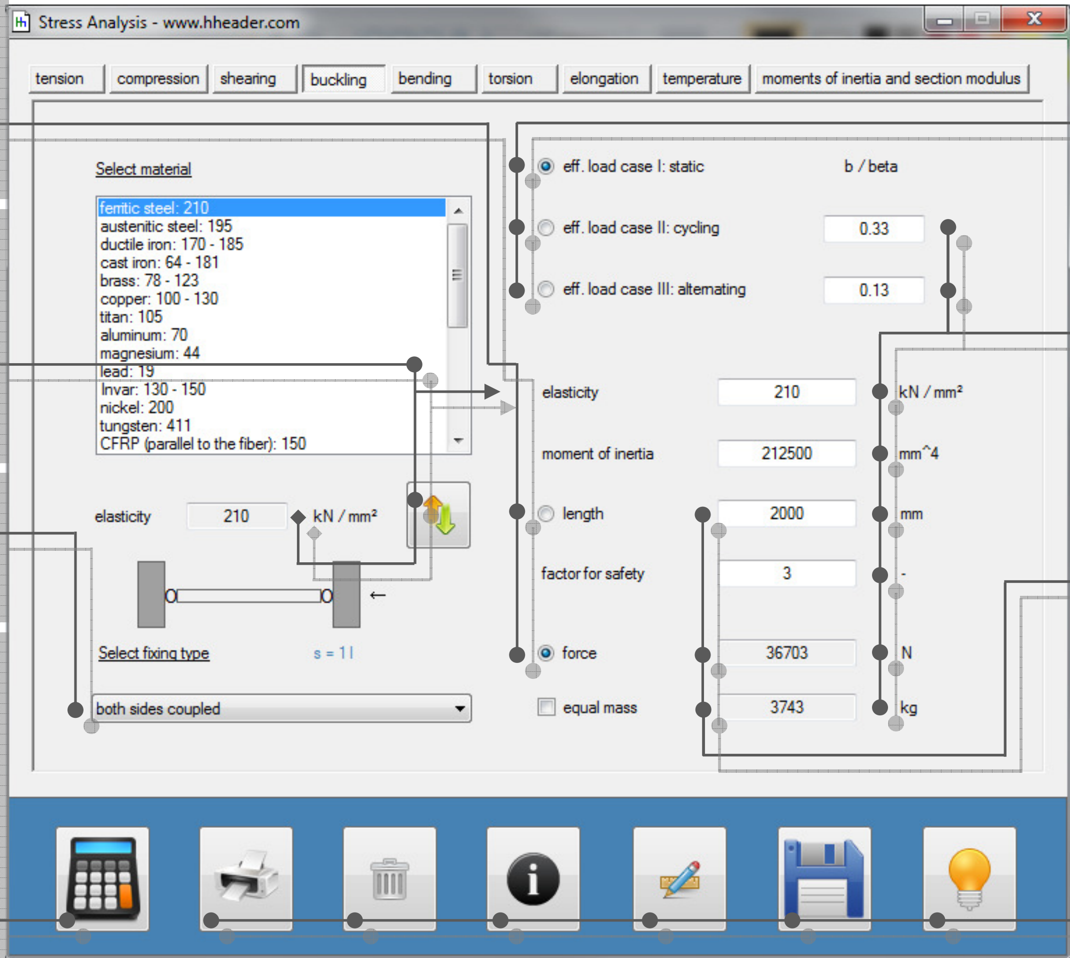


Figure 154: form stress analysis - buckling

Step 3:
Select the load case
By clicking on the corresponding *RadioButton* I can choose the effective load case for the calculations. There are three cases provided with corresponding factors.

Step 5:
Fill the Input-*TextBoxes*
I enter the values for the input variables. I should respect the variable limits and take care that the entered values are numeric.

Step 7:
Check result
After clicking the Calculate-Button I can check the result.

Step 8:
Further actions
After the calculation I can have the following options: Print Data, Erase Data, Program Information, Notes, Save or Restore Values. While printing a new calculation is done automatically. Clicking the Erase-Button will empty all the *TextBoxes* at once.

Step 4:
Select the variable to be calculated
By clicking on the corresponding *RadioButton* I can choose the variable to be calculated. It is like executing an internal conversion of the equation.

Step 1: (option)
Select a material
I can select the material in order to display the corresponding yield stress. I can transfer the value for the yield stress into the corresponding *TextBox* by clicking the transfer button.

Step 2:
Select the fixing type
I can select the fixing type. Six different types are provided.

Step 6:
Calculate result
After I entered the input values I can calculate the result. Before the calculation starts, all the input values are checked by an internal routine. Whenever entered values decrease the corresponding min limits or increase the corresponding max limits or are not numeric there will be a message according to the fault. The values will be corrected automatically by the internal routine.

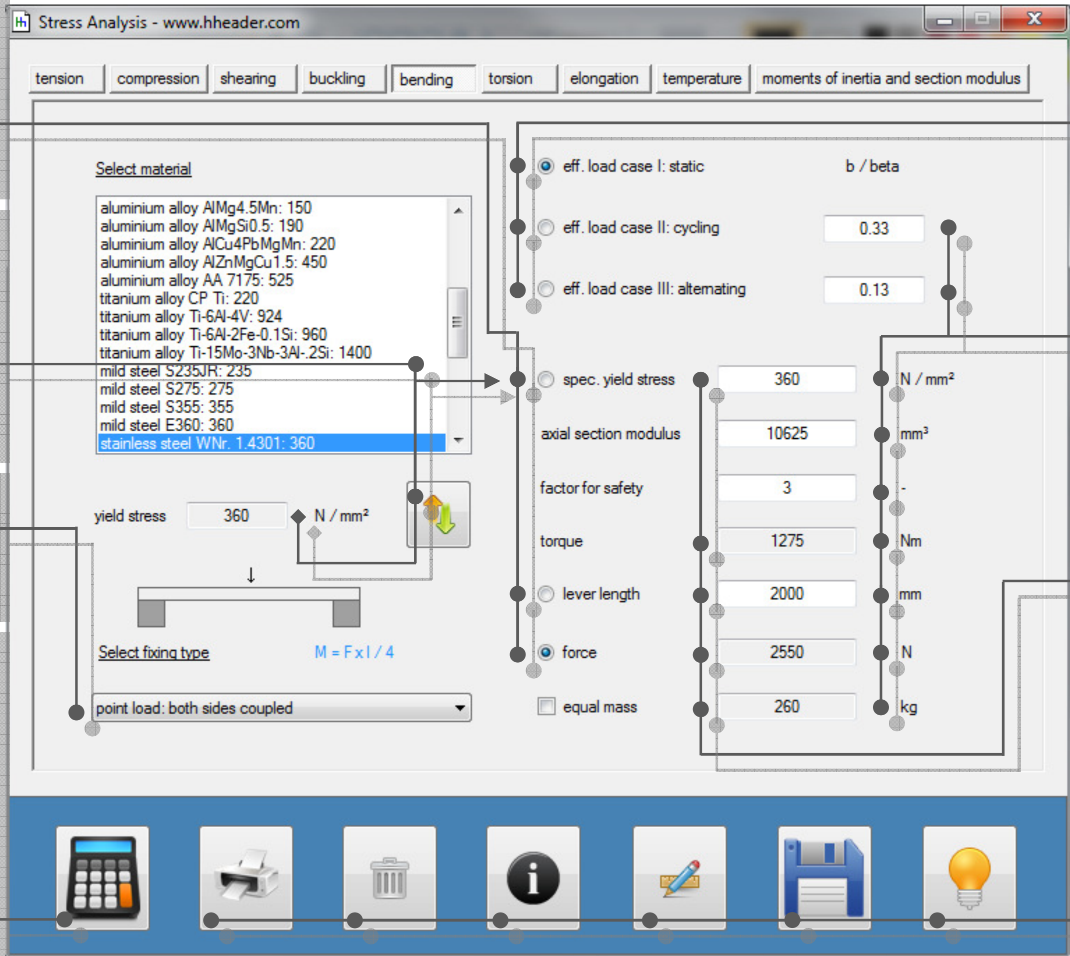


Figure 155: form stress analysis - bending

Step 3:
Select the load case
By clicking on the corresponding *RadioButton* I can choose the effective load case for the calculations. There are three cases provided with corresponding factors.

Step 5:
Fill the Input-TextBoxes
I enter the values for the input variables. I should respect the variable limits and take care that the entered values are numeric.

Step 7:
Check result
After clicking the Calculate-Button I can check the result.

Step 8:
Further actions
After the calculation I can have the following options: Print Data, Erase Data, Program Information, Notes, Save or Restore Values. While printing a new calculation is done automatically. Clicking the Erase-Button will empty all the *TextBoxes* at once.

Step 2:
Select the variable to be calculated
By clicking on the corresponding *RadioButton* I can choose the variable to be calculated. It is like executing an internal conversion of the equation.

Step 1: (option)
Select a material
I can select the material in order to display the corresponding yield stress. I can transfer the value for the yield stress into the corresponding *TextBox* by clicking the transfer button.

Step 5:
Calculate result
After I entered the input values I can calculate the result. Before the calculation starts, all the input values are checked by an internal routine. Whenever entered values decrease the corresponding min limits or increase the corresponding max limits or are not numeric there will be a message according to the fault. The values will be corrected automatically by the internal routine.

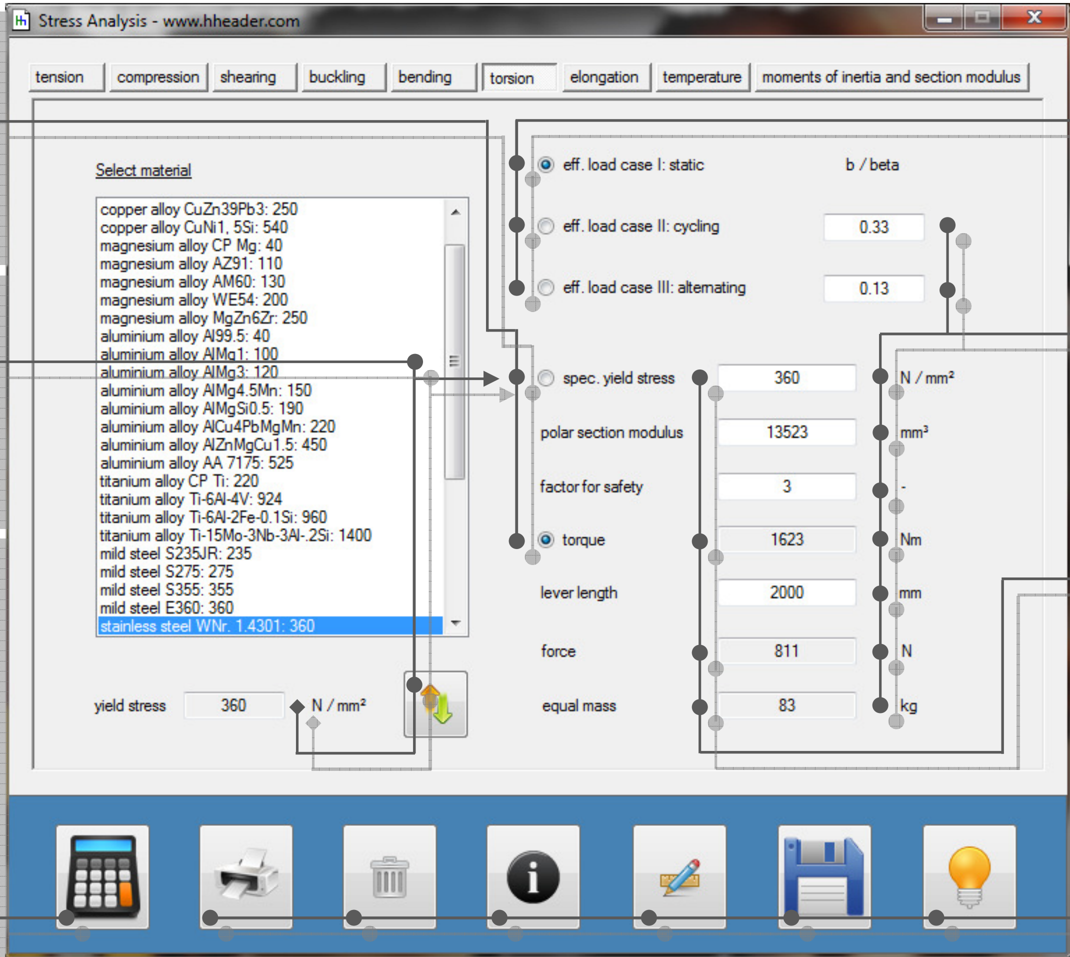


Figure 156: form stress analysis - torsion

Step 3:
Select the load case
By clicking on the corresponding *RadioButton* I can choose the effective load case for the calculations. There are three cases provided with corresponding factors.

Step 4:
Fill the Input-*TextBoxes*
I enter the values for the input variables. I should respect the variable limits and take care that the entered values are numeric.

Step 6:
Check result
After clicking the Calculate-Button I can check the result.

Step 7:
Further actions
After the calculation I can have the following options: Print Data, Erase Data, Program Information, Notes, Save or Restore Values. While printing a new calculation is done automatically. Clicking the Erase-Button will empty all the *TextBoxes* at once.

Step 1: (option)
Select elasticity
I can select the material in order to display the corresponding elasticity. I can transfer the value for the elasticity into the corresponding *TextBox* by clicking the transfer button.

Step 2: (option)
Select poison number
I can select the material in order to display the corresponding poisson number. I can transfer the value for the number into the corresponding *TextBox* by clicking the transfer button.

Step 5:
Calculate result
After I entered the input values I can calculate the result. Before the calculation starts, all the input values are checked by an internal routine. Whenever entered values decrease the corresponding min limits or increase the corresponding max limits or are not numeric there will be a message according to the fault. The values will be corrected automatically by the internal routine.

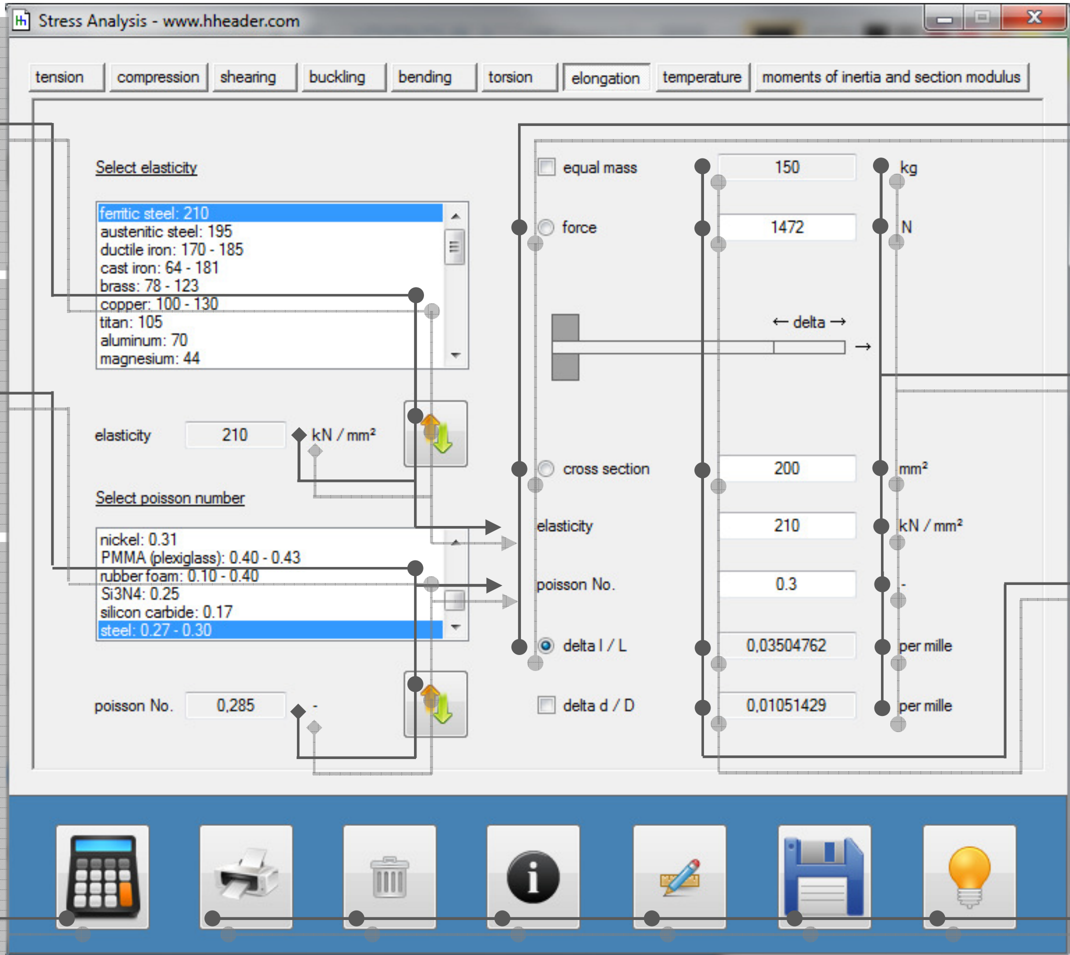


Figure 157: form stress analysis - elongation

Step 3:
Select the variable to be calculated
By clicking on the corresponding *RadioButton* I can choose the variable to be calculated. It is like executing an internal conversion of the equation.

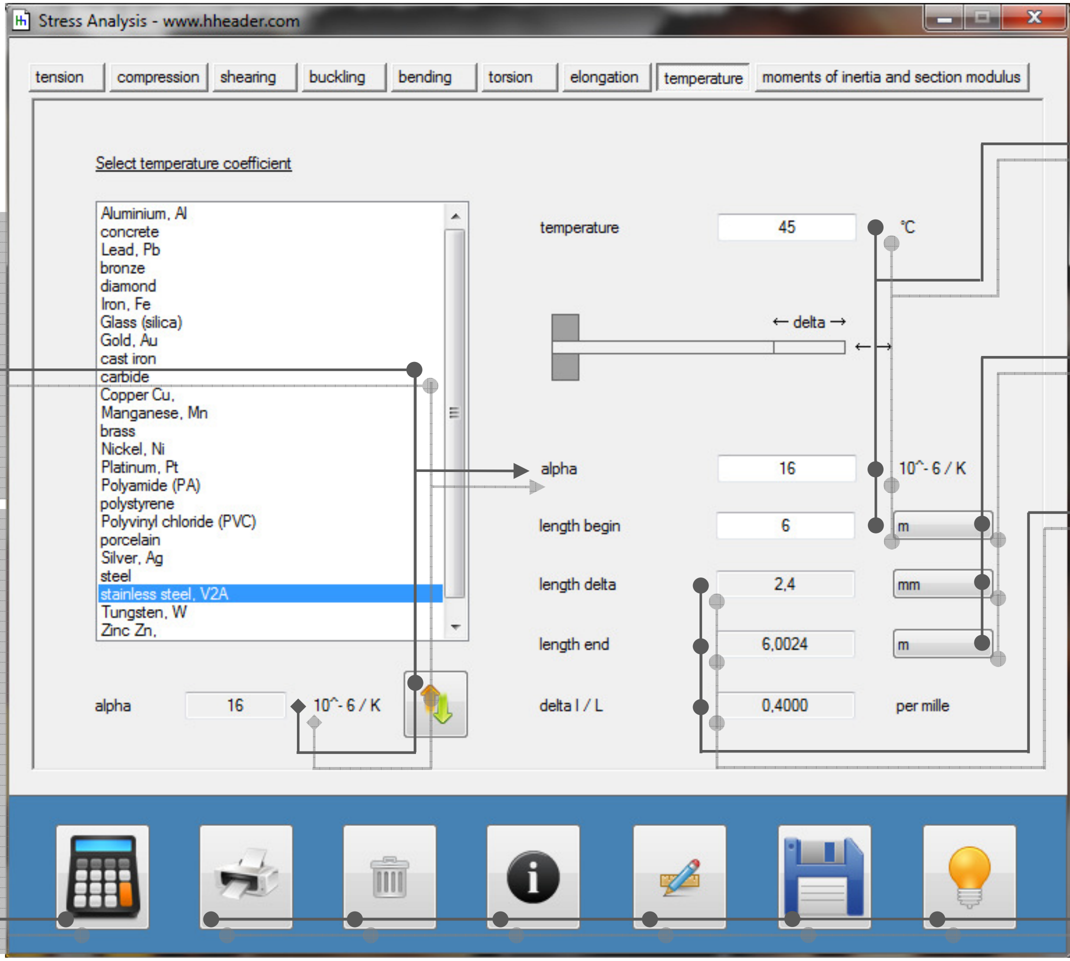
Step 4:
Fill the Input-*TextBoxes*
I enter the values for the input variables. I should respect the variable limits and take care that the entered values are numeric.

Step 6:
Check result
After clicking the Calculate-Button I can check the result.

Step 7:
Further actions
After the calculation I can have the following options: Print Data, Erase Data, Program Information, Notes, Save or Restore Values. While printing a new calculation is done automatically. Clicking the Erase-Button will empty all the *TextBoxes* at once.

Step 1: (option)
Select a material
I can select the material in order to display the corresponding temperature coefficient. I can transfer the value for the temperature coefficient into the corresponding *TextBox* by clicking the transfer button.

Step 4:
Calculate result
After I entered the input values I can calculate the result. Before the calculation starts, all the input values are checked by an internal routine. Whenever entered values decrease the corresponding min limits or increase the corresponding max limits or are not numeric there will be a message according to the fault. The values will be corrected automatically by the internal routine.



Step 2:
Fill the Input-*TextBoxes*
I enter the values for the input variables. I should respect the variable limits and take care that the entered values are numeric.

Step 3:
Select the units
I can select the units for the different length values.

Step 5:
Check result
After clicking the Calculate-Button I can check the result.

Step 6:
Further actions
After the calculation I can have the following options: Print Data, Erase Data, Program Information, Notes, Save or Restore Values. While printing a new calculation is done automatically. Clicking the Erase-Button will empty all the *TextBoxes* at once.

Figure 158: form stress analysis - temperature

Step 4:
Enter the number of support points
I enter the number of support points. It is multiplied by the cross section.

Info: For the C-, L- and T-Profile there are principally two different kinds of section modulus existing. There are two buttons (min, max) provided which will appear if one of these profiles is selected. The Min-Button is for the low values and the Max-Button is for the high values.

Step 1:
Select a profile
I can select the profile type for the calculations of the moments of inertia and the section modulus. The corresponding measures will be displayed in coherence to the selected profile.

Step 2:
Select the gravity constant
I can select the gravity constant by location. This variable is important for the calculation of the mass that is equal to the force. This depends on the gravity constant. Usually "earth" should be selected.

Step 5:
Calculate result
After I entered the input values I can calculate the result. Before the calculation starts, all the input values are checked by an internal routine. Whenever entered values decrease the corresponding min limits or increase the corresponding max limits or are not numeric there will be a message according to the fault. The values will be corrected automatically by the internal routine.

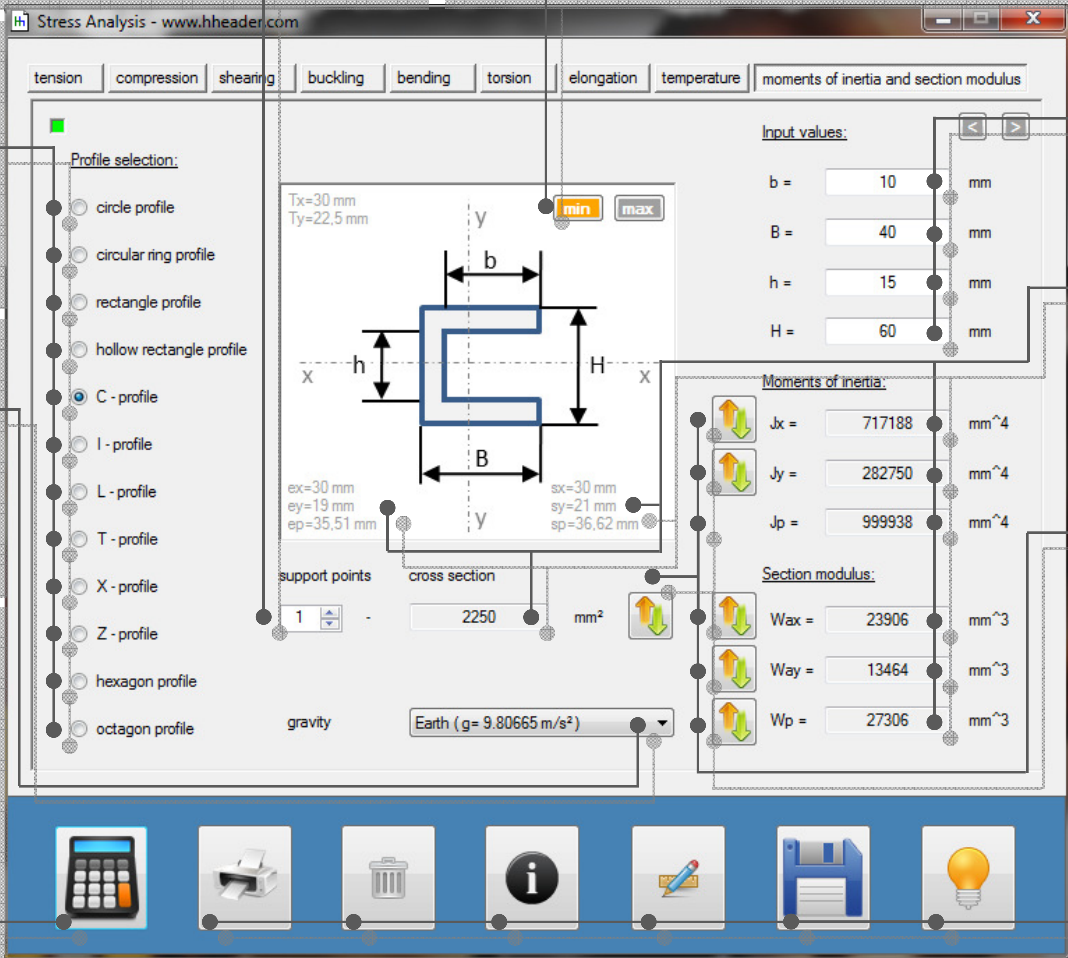


Figure 159: form stress analysis - moments of inertia and section modulus

Step 3:
Fill the Input-*TextBoxes*
I enter the values for the input variables. I should respect the variable limits and take care that the entered values are numeric.

Step 6:
Check result
After clicking the Calculate-Button I can check the result.

Step 7:
Transfer values
By clicking the corresponding transfer button, I can transfer the value into the corresponding *TextBoxes*. A list is provided in the description at the beginning of the chapter.

Step 8:
Further actions
After the calculation I can have the following options: Print Data, Erase Data, Program Information, Notes, Save or Restore Values. While printing a new calculation is done automatically. Clicking the Erase-Button will empty all the *TextBoxes* at once.

11.3. Fastening Torques

11.3.1. Purpose (What can it be used for? What can it not be used for?)

The program is part of category 6 – mechanics. Of course screws and bolts should be tightened with the prescribed fastening torques. For the mounting works on site protocols for the proper fastening of the used screws and bolts are often demanded. If not otherwise stated or specified the fastening torques which are valid in general can be determined by this program. Regarding the basis for the determination the fastening torques are divided into two different types.

Type Two (left side):

Fastening torques for the connection of flange joints, where the gasket type and the thread diameter of the screw or bolt are basis for the determination. The program provides internal tables for two different groups of gaskets.

Type One (right side):

Fastening torques for the mounting of steel constructions, supports and consoles, where the quality and the thread diameter of the screw or bolt are basis for the determination. The program provides internal tables for threads with a friction coefficient of $\mu=0.125$.

In the first the type has to be selected whether the fastening torques are required for the mounting of steel constructions, supports and consoles (Type One – right side) or for the joining of pipe flanges (Type Two – left side). For this selection corresponding *RadioButtons* are provided in the upper part of the form.

Regarding Type One (right side) the fastening torques for screws and bolts depend mainly on the following two criteria. These are the quality and the thread size of the screw or bolt. The program provides a selection of metric threads and a selection of qualities. In order to get back a proper result both selections have to be done according to the actual case.

Beside the fastening torque also the spanner number as well as the tenacity and the yield stress for the selected items are shown as output variables. The quality of the thread has to be selected according to the used screws or bolts. Usually it is given by a number (X.Y) on the bolt head. The quality at least gives back the tenacity and the yield stress. Thereby the tenacity is equal to the value before the dot multiplied by 100 and the yield stress is equal to the number before the dot multiplied by the number after the dot multiplied by 10. The unit for tenacity and yield stress is Newton per millimeter square (N / mm^2). A table with the established qualities is shown on the next page.

No.	Quality	Tenacity (Rm)	Yield Stress (Re)
1	3.6	300 N / mm²	180 N / mm²
2	4.6	400 N / mm²	240 N / mm²
3	4.8	400 N / mm²	320 N / mm²
4	5.6	500 N / mm²	300 N / mm²
5	5.8	500 N / mm²	400 N / mm²
6	6.8	600 N / mm²	480 N / mm²
7	8.8	800 N / mm²	640 N / mm²
8	10.9	1000 N / mm²	900 N / mm²
9	12.9	1200 N / mm²	1080 N / mm²

Figure 160: table for tenacity and yield stress according to the quality

The thread dimension has to be selected according to the used screws or bolts. The type of thread is “M” for all the listed threads. The number after the “M” is equal to the thread diameter. For small threads the tapping drill hole is approximately 0.8 by the thread diameter. The outer diameter and the tapping hole diameter are listed in the table.

No.	Thread	Outer Diameter	Tapping Hole
1	M4	4 mm	3.3 mm
2	M5	5 mm	4.2 mm
3	M6	6 mm	5.0 mm
4	M8	8 mm	6.8 mm
5	M10	10 mm	8.5 mm
6	M12	12 mm	10.2 mm
7	M14	14 mm	12.0 mm
8	M16	16 mm	14.0 mm
9	M18	18 mm	15.5 mm
10	M20	20 mm	17.5 mm
11	M22	22 mm	19.5 mm
12	M24	24 mm	21.0 mm
13	M27	27 mm	24.0 mm
14	M30	30 mm	26.5 mm
15	M33	33 mm	29.5 mm
16	M36	36 mm	32.0 mm
17	M39	39 mm	35.0 mm
18	M42	42 mm	37.5 mm
19	M45	45 mm	40.5 mm
20	M48	48 mm	43.0 mm
21	M52	52 mm	47.0 mm
22	M56	56 mm	51.5 mm
23	M60	60 mm	54.5 mm
24	M64	64 mm	58.0 mm
25	M68	68 mm	61.5 mm

Figure 161: table stress thread measures

Regarding Type Two (left side) the fastening torques for screws and bolts depend mainly on two criteria. These are the gasket type and the thread size of the screw or bolt. The program provides a selection of the established metric threads for screws and bolts used for joining flanges and a selection for gaskets. In order to get back a proper result both selections have to be done according to the actual case.

Regarding the used gaskets there are two different groups defined as follows:

Gaskets Group A:

- flat gaskets,
- flat seals,
- ring gaskets.

Gaskets Group B:

- gaskets with tongue and groove face,
- grooved metal gaskets,
- spiral wound gaskets.

The corresponding fastening torques are listed in the table below.

No.	Thread	Gasket Group A	Gasket Group B
1	M12	50 Nm	50 Nm
2	M16	125 Nm	80 Nm
3	M20	240 Nm	150 Nm
4	M24	340 Nm	200 Nm
5	M27	500 Nm	250 Nm
6	M30	700 Nm	300 Nm

No.	Thread	Gasket Group A	Gasket Group B
7	M33	900 Nm	500 Nm
8	M36	1200 Nm	750 Nm
9	M39	1400 Nm	900 Nm
10	M45	2000 Nm	1200 Nm
11	M52	3000 Nm	1600 Nm

Figure 162: table for fastening torques according to the gasket type

In the lower part of the form general calculations for torques are provided. This can be helpful for a proper imagination of the coherences between force, lever length and the resulting torque. For the same reason also a mass that would result the given or calculated force value by gravity is displayed. Therefore the earth gravity is considered.

All of the variables which are equal mass respectively force, lever length and torque can be selected as output variables. Therefore equal mass and force are handled as one pair of variables. Thus the residual two are input variables. By clicking the Calculate-Button the variables will be calculated.

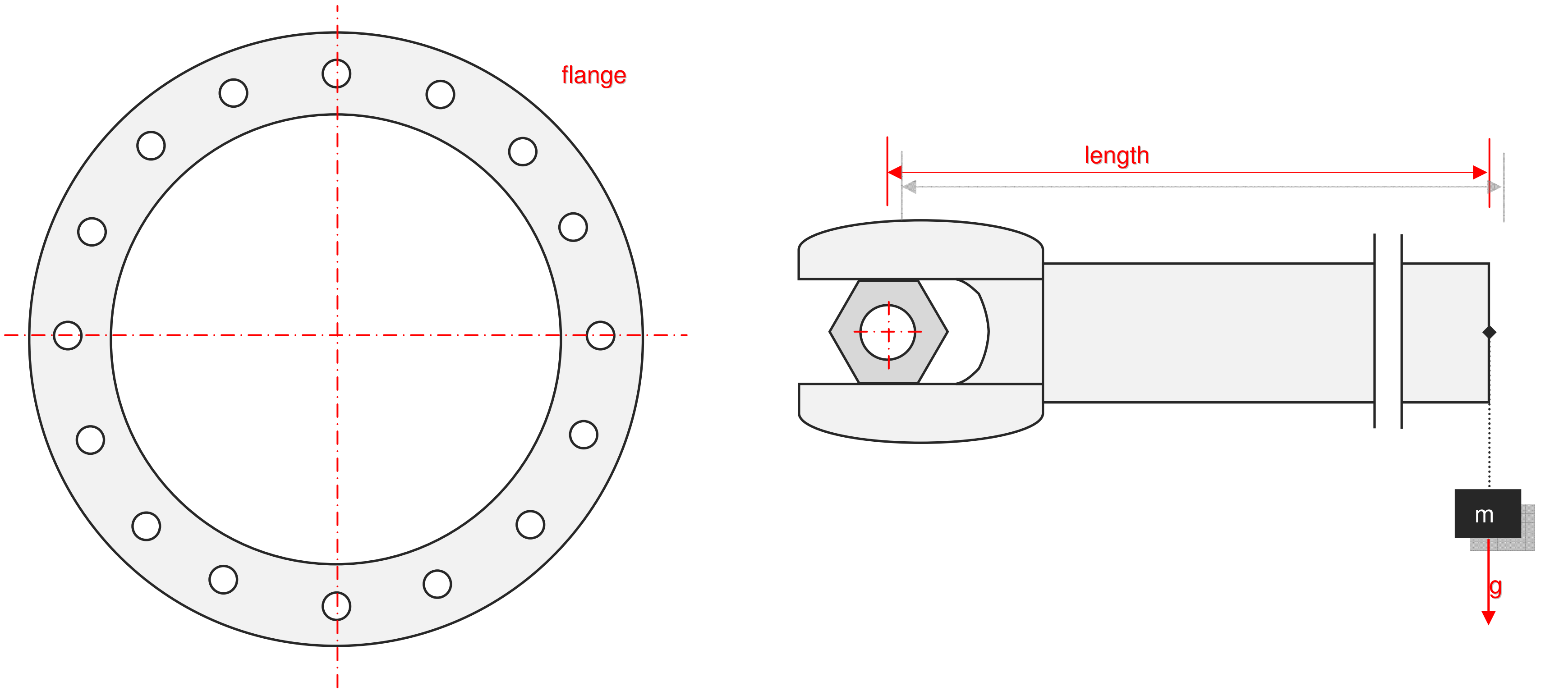


Figure 163: sketch fastening torques

11.3.2. Variables (What are the input and output values? What are their limits?)

thread

It is the measure of the thread which is equal to the outer diameter of the screw or bolt in millimeter. The type of thread is “M” for all the listed threads. For small threads the tapping drill hole is approximately 0.8 by the thread diameter. The variable is entered by selection.

The variable type is Input.
The unit is millimeter [mm].
The minimum limit is M4.
The maximum limit is M68.
The variable has no replacement value.
The number of digits is 3.

quality

It is the quality of the screw or bolt. This is given by at least two numbers. They are separated by a dot. The first number multiplied by 100 gives back the tenacity in Newton per millimeter square. The number before the dot multiplied by the number after the dot multiplied by 10 gives back the yield stress in Newton per millimeter square. The variable is entered by selection.

The variable type is Input.
The variable has no unit [-].
The minimum limit is 3.6.
The maximum limit is 12.9.
The variable has no replacement value.
The number of digits is 4.

torque

It is the nominal fastening torque that is designated according to the selected quality for the screw or bolt or according to the flange type.

The variable type is Output.
The unit is Newton by meter [Nm].
There is no defined minimum limit for output variables.
There is no defined maximum limit for output variables.
There is no defined replacement value for output variables.
There is no defined number of digits for output variables.

spanner No.

It is the number of the spanner that is usually fitting for the screw or bolt. The value is equal to the spanner width in millimeter.

The variable type is Output.
The unit is millimeter [mm].
There is no defined minimum limit for output variables.
There is no defined maximum limit for output variables.
There is no defined replacement value for output variables.
There is no defined number of digits for output variables.

tenacity

It is the tenacity of the screw or bolt that is according to the selected quality. The first number multiplied by 100 gives the tenacity for the screw or bolt in Newton per millimeter square.

The variable type is Output.
The unit is Newton per millimeter square [N / mm²].
There is no defined minimum limit for output variables.
There is no defined maximum limit for output variables.
There is no defined replacement value for output variables.
There is no defined number of digits for output variables.

yield stress

It is the yield stress of the screw or bolt that is according to the selected quality. The number before the dot multiplied by the number after the dot multiplied by 10 gives back the yield stress in Newton per millimeter square.

The variable type is Output.
The unit is Newton per millimeter square [N / mm²].
There is no defined minimum limit for output variables.
There is no defined maximum limit for output variables.
There is no defined replacement value for output variables.
There is no defined number of digits for output variables.

equal mass

It is the mass that would cause the equal value for the force by gravity. For this a gravity of 9.81 m / s² is considered. The mass calculation is for evaluation purpose.

The variable type is Input or Output.
The unit is kilogram [kg].
The minimum limit is 0.0001.
The maximum limit is 99999999.
The replacement value is 100.
The number of digits is 8.

force

It is the force that is base for the calculation of the torque which is the product of the force and the length of the lever.

The variable type is Input or Output.
The unit Newton [N].
The minimum limit is 0.0001.
The maximum limit is 99999999.
The replacement value is 100.
The number of digits is 8.

lever

It is the length of the lever that is base for the calculation of the torque which is the product of the force and the length of the lever.

The variable type is Input or Output.
The unit is meter [m].
The minimum limit is 0.0001.
The maximum limit is 99999999.
The replacement value is 100.
The number of digits is 8.

torque

It is the torque as result of the product of the base variables force and lever length.

The variable type is Input or Output.
The unit is Newton by meter [Nm].
The minimum limit is 0.0001.
The maximum limit is 99999999.
The replacement value is 100.
The number of digits is 8.

11.3.3. Operation (How can it be used? How to proceed?)

Step 1:
Select the use case
I can select whether the torque is requested for flange connections or steel constructions.

Step 2: **(option)**
Select gasket type
I can select the group for the used gasket.

Step 3: **(option)**
Select the thread quality
I can select the quality of the thread. The quality at least gives back the tenacity and the yield stress. Thereby the tenacity is equal to the value before the dot by 100 and the yield stress is equal to the number before the dot by the number the after the dot by 10.

Step 4:
Select the thread dimension
I can select the thread dimension. The type of thread is “M” for all the listed threads. The number after the “M” is the thread diameter. For small threads the tapping drill hole is approximately 0.8 by the thread diameter.

Step 5:
Select the variable to be calculated
By clicking on the corresponding *RadioButton* I can choose the variable to be calculated. It is like executing an internal conversion of the equation.

Step 6:
Fill the Input-*TextBoxes*
I enter the values for the input variables. I should respect the variable limits and take care that the entered values are numeric.

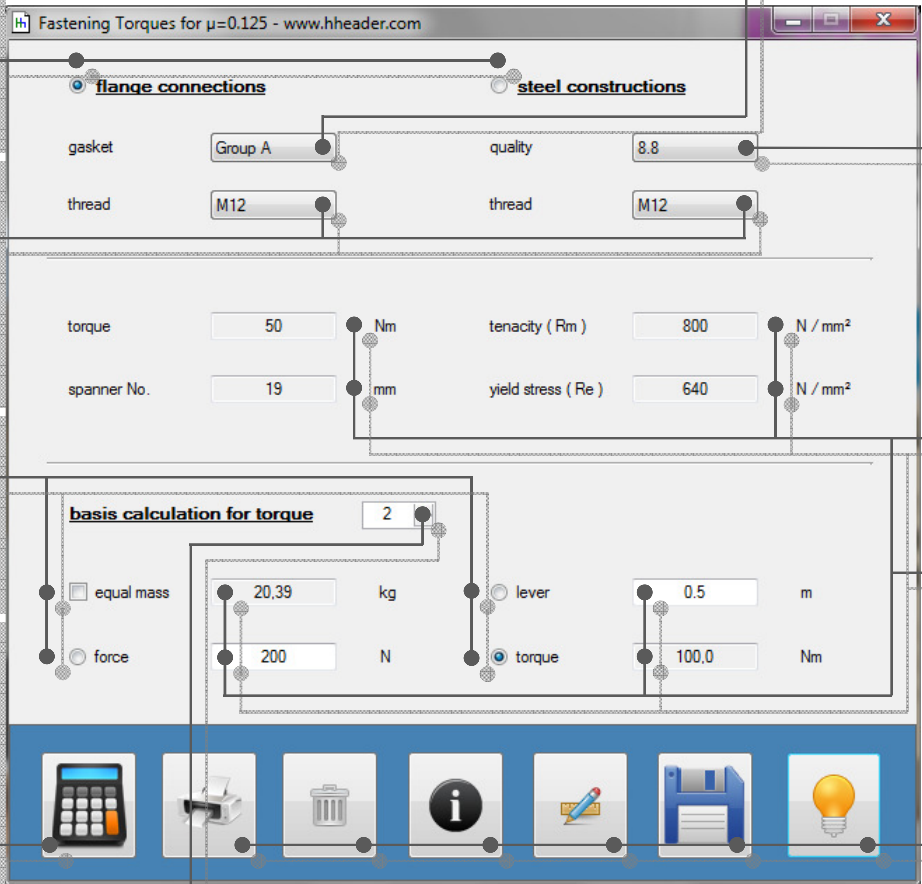


Figure 164: form fastening torques

Step 7:
Enter the number of decimal places
I enter the number of decimal places for the output variables.

Step 8:
Calculate result
After I entered the input values I can calculate the result. Before the calculation starts, all the input values are checked by an internal routine. Whenever entered values decrease the corresponding min limits or increase the corresponding max limits or are not numeric there will be a message according to the fault. The values will be corrected automatically by the internal routine.

Step 9:
Check result
After clicking the Calculate-Button I can check the result.

Step 10:
Further actions
After the calculation I can have the following options: Print Data, Erase Data, Program Information, Notes, Save or Restore Values. While printing a new calculation is done automatically. Clicking the Erase-Button will empty all the *TextBoxes* at once.

11.4. Engine Vibration

11.4.1. Purpose (What can it be used for? What can it not be used for?)

The program is part of category 6 – mechanics. Different rules (e.g. the German Rule VDI 2056) define the permissible vibration rates for different aggregates on site. The vibration rates for operated aggregates have to be determined and evaluated regularly. Therefore special instruments are used that measure the deflection of the aggregate while it is in operation. The relevant unit is millimeter per second [mm / s]. Depending on the type, respectively the power rate of the aggregate, there are corresponding limit values defined for an accurate evaluation of the deflection.

According to the German Rule VDI 2056 there are four categories of engines divided up that have separate limit values for the evaluation of the vibrations.

- **Category K:**
  small size engines up to 15 kW
- **Category M:**
  medium size engines up to 75 kW
- **Category G:**
  big engines with accurate adjusted console
- **Category T:**
  turbo engines with accurate adjusted console

Depending on the engine category there are different limits relevant for the allowed deflection. Regarding the evaluation of the deflection there are four levels designated.

- in good condition
- in proper condition
- still permissible
- not permissible / maintenance required

The following table shows the mentioned limit values and how the measured results have to be evaluated.

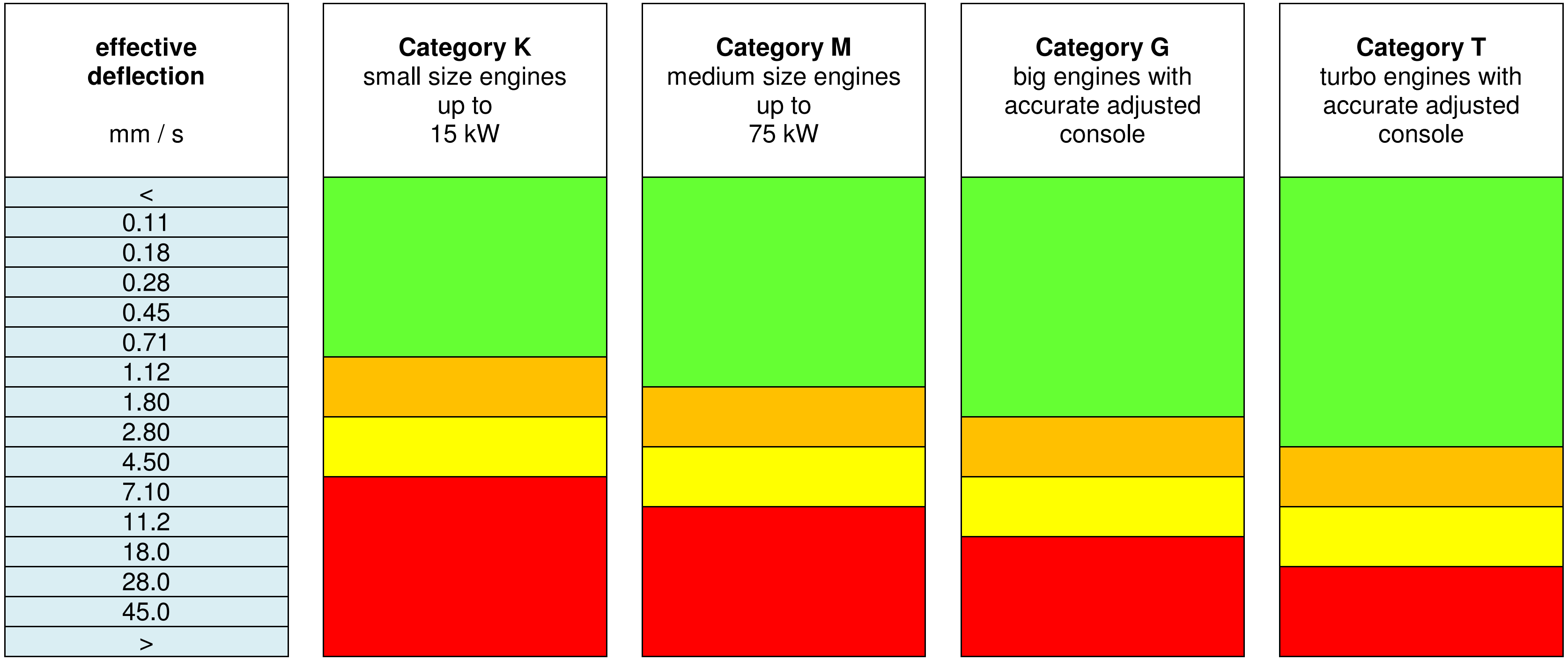


Figure 165: sketch engine vibrations

The evaluation is done internally by the program. The user has to take the corresponding measures with a proper instrument. Usually the measures are taken for the front and rear side of the engine. The temperatures of the front and rear bearing shields are also measured. The maximum allowed temperatures can be very different due to the type and size of the engine. The critical temperatures for the bearings are normally given in manufacturer manual. Anyhow the program will generate a temperature alarm, in case if the measured temperature is more than 70°C. In this case the supplier specification should be checked regarding the maximum allowed bearing temperature. Maintenance works on the bearings might be required. These works should be according the manufacturers manual respectively in agreement with the manufacturers technical support.

Regarding the temperature the following indications are provided. On the left side of the table below the messages and indications for the front and rear bearing are displayed. On the right side of the table the messages and indications for the evaluation of both bearings are displayed.

Messages and indications for the front and rear bearing:

- temperature ok (green)
- temperature alarm (red)

Messages and indications for the evaluation of both bearings:

- temperature ok – normal range (green)
- High temperature – check supplier specification! (red)

The form itself is divided up into three parts (upper part, middle, lower part). In the upper part of the form the values and the evaluation for the front side of the engine are shown. The values and the evaluation for the rear side of the engine are shown in the middle of the form. For both cases the deflections have to be measured horizontal and vertical. Also the temperature at the bearing should be taken. The values for the deflections and the temperature can be entered on the left side. The messages and indications are placed on the right side. They are activated accordingly after clicking the Calculate-Button. In the lower part of the form the evaluation with the corresponding messages and indications for both sides (front and rear) of the engine are shown. Therefore the results of the single measurements for front and rear side are superposed. That means at least, if one of the sides (front or rear) requires maintenance works, this will also be shown in the lower part of the form.

The printout can be used as a protocol.

11.4.2. Variables (What are the input and output values? What are their limits?)

horizontal (deflection)

It is the horizontal deflection that is measured at the engine respectively at the console of the engine.

The variable type is Input.
The unit is millimeter per second [mm / s].
The minimum limit is 0.0001.
The maximum limit is 100.
The replacement value is 1.2.
The number of digits is 6.

vertical (deflection)

It is the vertical deflection that is measured at the engine respectively at the console of the engine.

The variable type is Input.
The unit is millimeter per second [mm / s].
The minimum limit is 0.0001.
The maximum limit is 100.
The replacement value is 1.2.
The number of digits is 6.

temperature

It is the temperature that is measured at the bearings respectively at the bearing shields of the engine that is focus for the measurements. The greatest temperature value of all measured bearings has to be entered.

The variable type is Input.
The unit is degree Celsius [°C].
The minimum limit is -50.
The maximum limit is 500.
The replacement value is 20.
The number of digits is 6.

11.4.3. Operation (How can it be used? How to proceed?)

Step 2:
Fill the Input-*TextBoxes*
I enter the values for the input variables. I should respect the variable limits and take care that the entered values are numeric.

Step 1:
Select the engine category
I can select the engine category according to the range of power rates. There are four categories provided for small, medium, big and turbo engines. The vibration measures for the limits and the evaluation are depending on the engine category.

Step 3:
Calculate result
After I entered the input values I can calculate the result. Before the calculation starts, all the input values are checked by an internal routine. Whenever entered values decrease the corresponding min limits or increase the corresponding max limits or are not numeric there will be a message according to the fault. The values will be corrected automatically by the internal routine.

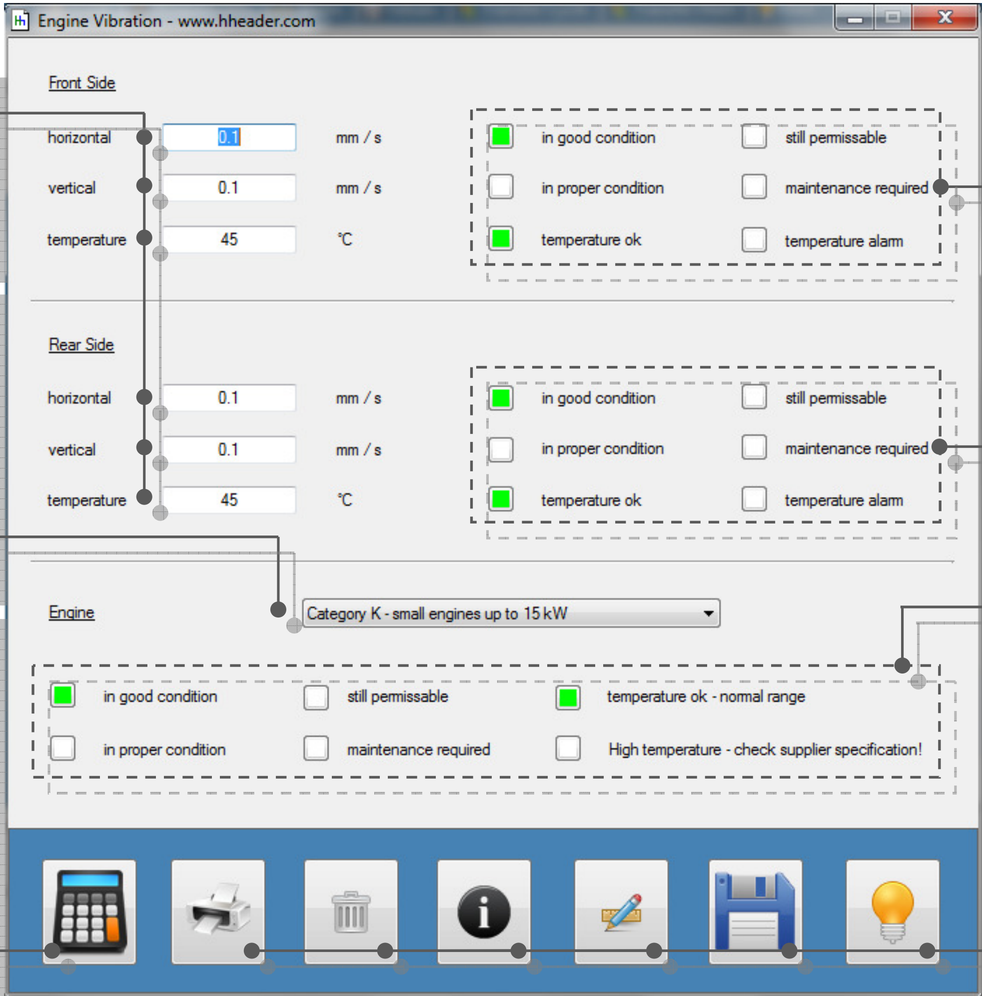


Figure 166: form engine vibration

Step 4:
Check result for the Front Side
After clicking the Calculate-Button I can check the result for the Front Side.

Step 5:
Check result for the Rear Side
After clicking the Calculate-Button I can check the result for the Rear Side.

Step 6:
Check the total result
After clicking the Calculate-Button I can check the result for the complete engine.

Step 7:
Further actions
After the calculation I can have the following options: Print Data, Erase Data, Program Information, Notes, Save or Restore Values. While printing a new calculation is done automatically. Clicking the Erase-Button will empty all the *TextBoxes* at once.

11.5. Welding Current

11.5.1. Purpose (What can it be used for? What can it not be used for?)

The program is part of category 6 – mechanics. The program provides internal tables giving back the corresponding welding currents for arc welding with electrodes. The basis table values for the current are for unalloyed or low alloy steel types. For alloyed or high-alloy steel types the values have to be reduced because of the increased core rod resistance. The real proper current has to be adjusted in practice. For documentation purpose there are factors provided for each table. They can be set according to the in practice determined values. Afterwards the values can be stored in a data set. Thereby it is possible to create individual data sets for many different use cases. The program form consists of nine different *TabPages*.

(1) Introduction:

The introduction gives an overview about the program content. For each of the *TabPages* there is a link button and a short description provided in order to give a first orientation. The form contains further three *TabPages* for revision purposes, four tables for the determination of welding currents and one table for handling data sets.

(2) Welding Positions:

In the rules (e.g. according to the German ISO 6947) there are different welding positions defined. The positions (PA, PB, PC, PD, PE, PF, PG, PH, PJ, PK, H-L045 and J-L045) are declared with the help of a sketch for revision purposes.

(3) Welding Seams:

Some of the established welding seams (like square butt weld, single-V but weld, single-Y seam, double-V butt weld, single-U butt weld, hollow seam) are shown and declared by corresponding sketches for revision purposes.

(4) Electrode Types:

Welding electrodes need to have different properties for different use cases. This is why there are different types of electrodes existing. The properties can be identified via the electrode designation. The corresponding selections are provided according to the possible designations for revision purposes.

(5) Table 1: (electrode diameter)

The welding currents are displayed according to the selected electrode diameter. The electrode length and the recommended welding current range for the selected electrode diameter are resulting and can be assumed as a basic setting. Further an empirical formula for the recommended current range is shown.

(6) Table 2: (wall thickness)

The welding currents are displayed according to the selected wall thickness. It is the wall thickness of the steel pipe that should be welded. The selection is divided up in root, hotpass, middle bead and top bead. The basic values are provided for a single-V but weld, the welding position PG and the electrode covering type C.

(7) Table 3: (measure “a”)

The welding currents are displayed according to the selected measure “a”. The measure “a” is a value for the thickness of the weldseam. The basic values are provided for a hollow seam (T), the welding positions PG, PB or PF and electrode types RC, RR, RR160, B.

(8) Table 4: (plate thickness)

The welding currents are displayed according to the selected plate thickness. It is the thickness of the steel sheet or steel plate that should be welded. The basic values are provided for a single-V but weld, the welding positions PA or PF and electrode types RA, RB, B.

(9) Table 5: (User defined Data)

All values are displayed according to the stored user defined data sets. There are eight input criteria provided where the user can enter own data sets. Be aware that the defined values are just textual information and that there are no rules defined regarding the input philosophy.

The value for the welding current is recommended according to the selection. Be aware that this value is to be assumed as a basic setting. The real proper current has to be adjusted in practice. A factor can be determined by practical tests. The factor is the relation between the recommended base current and the new determined welding current. The factor multiplied by the base current results the new current value.

On the introduction *TabPage* it can be chosen between the different subprograms. There are two possibilities for the selection: by clicking the corresponding button or by clicking the corresponding *TabPage*. On the right side there are explanations shown for each of the subprograms. These should give a first orientation.

Welding Positions:

In the rules (e.g. according to the German EN ISO 6947) there are different welding positions defined. The positions (PA, PB, PC, PD, PE, PF, PG, PH, PJ, PK, H-L045 and J-L045) are declared with the help of a sketch for revision purposes. The ASME Code Section IX defines similar positions. Thereby it is divided up into butt weld (1G, 2G, 3Gu, 3Gd, 4G, 5Gu, 5Gd, 6Gu, 6Gd) and hollow weld (1F, 1FR, 2F, 2FR, 4F, 5Fd, 5Fu).

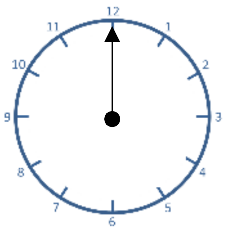
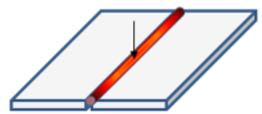
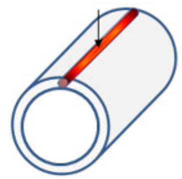
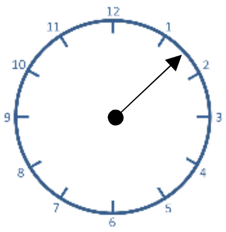
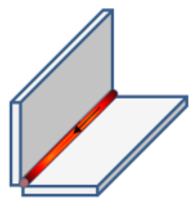
PA	PA is the welding position where the seam is welded horizontal on the top side of the work piece. The relative position is at 12:00 o'clock. For this position there are two examples provided (two steel sheets and one pipe section). This welding position is similar to the ASME position 1G, 1F and 1FR.			
PB	PB is the welding position where the seam is welded horizontal at 45° from the top side of the work piece. The relative position is at 01:30 o'clock. For this position there are two examples provided (two steel sheets and one pipe section). This welding position is similar to the ASME position 2F and 2FR.			

Figure 167: sketches welding current – welding positions PA and PB

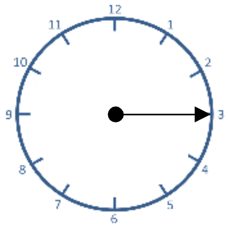
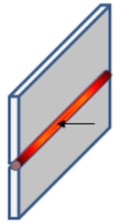
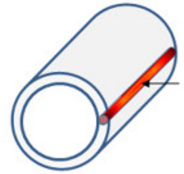
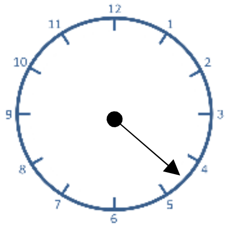
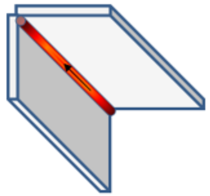
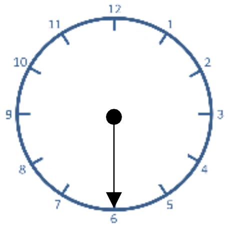
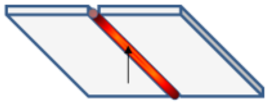
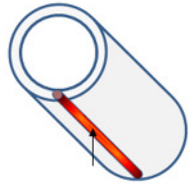
PC	PC is the welding position where the seam is welded horizontal at 90° from the top side of the work piece. The relative position is at 03:00 o'clock. For this position there are two examples provided (two steel sheets and one pipe section). This welding position is similar to the ASME position 2G.			
PD	PD is the welding position where the seam is welded horizontal at 135° from the top side of the work piece. The relative position is at 04:30 o'clock. For this position there are two examples provided (two steel sheets and one pipe section). This welding position is similar to the ASME position 4F.			
PE	PE is the welding position where the seam is welded horizontal at 180° from the top side of the work piece. The relative position is at 06:00 o'clock. For this position there are two examples provided (two steel sheets and one pipe section). This welding position is similar to the ASME position 4G.			

Figure 168: sketches welding current – welding positions PC to PE

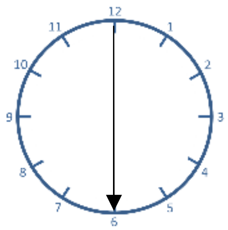
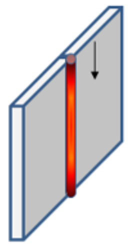
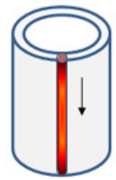
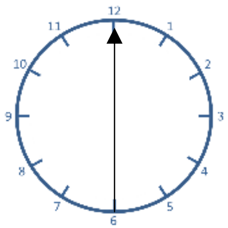
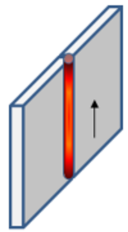
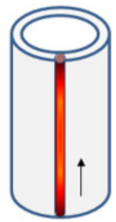
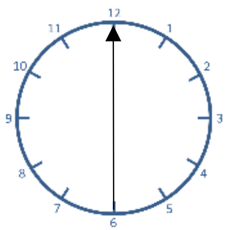
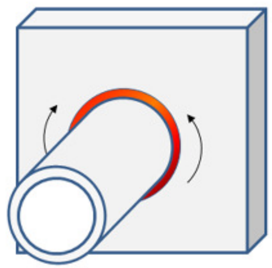
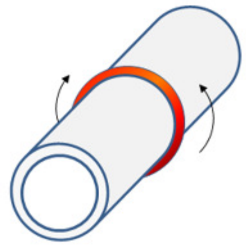
PF	PF is the welding position where the seam is welded vertical at 0° from the top side of the work piece in direction downwards (falling). The relative position is the axis from 12:00 to 06:00 o'clock. For this position there are two examples provided (two steel sheets and one pipe section). This welding position is similar to the ASME position 3Gu.			
PG	PG is the welding position where the seam is welded vertical at 180° from the top side of the work piece in direction upwards (raising). The relative position is the axis from 12:00 to 06:00 o'clock. For this position there are two examples provided (two steel sheets and one pipe section). This welding position is similar to the ASME position 3Gd.			
PH	PH is the welding position where the seam is welded circular at 180° from the top side of the work piece in direction upwards (raising) left and right side from the pipe. Thereby either pipe and sheet or two pipe sections are connected. The relative position is from 06:00 to 12:00 o'clock. For this position there are two examples provided (one steel sheet and one pipe section and two pipe sections). This welding position is similar to the ASME position 5Gu and 5Fu.			

Figure 169: sketches welding current – welding positions PF to PH

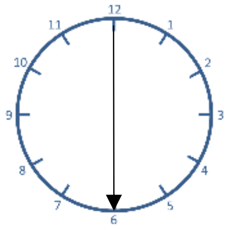
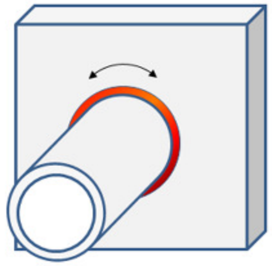
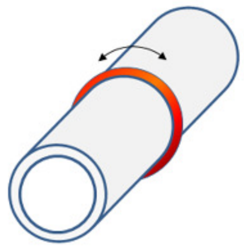
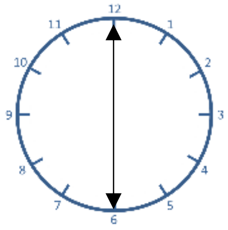
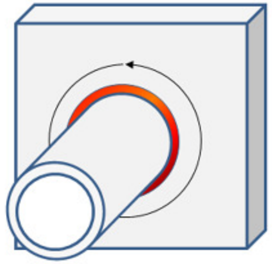
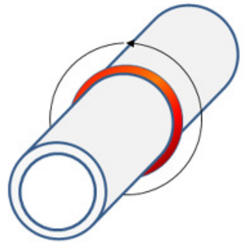
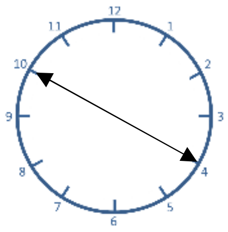
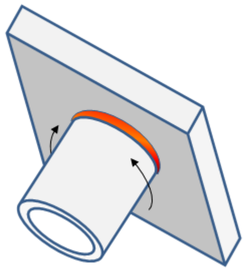
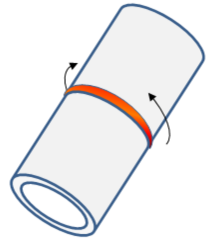
PJ	PJ is the welding position where the seam is welded circular at 0° from the top side of the work piece in direction downwards (falling) left and right side from the pipe. Thereby either pipe and sheet or two pipe sections are connected. The relative position is from 12:00 to 06:00 o'clock. For this position there are two examples provided (one steel sheet and one pipe section and two pipe sections). This welding position is similar to the ASME position 5Gd and 5Fd.			
PK	PK is the welding position where the seam is welded circular at 0° from the top side of the work piece in direction downwards (falling) left side from the pipe and in direction upwards (raising) right side from the pipe. Thereby either pipe and sheet or two pipe sections are connected. The relative position is from 12:00 to 12:00 o'clock. For this position there are two examples provided (one steel sheet and one pipe section and two pipe sections).			

Figure 170: sketches welding current – welding positions PJ and PK

H- L045	H-L045 is the welding position where the seam is welded circular at 180° from the top side of the work piece in direction upwards (raising) left and right side from the pipe. In addition to that the work piece itself is arranged with an angle of 45° to the work bench or to the ground floor. Thereby either pipe and sheet or two pipe sections are connected. The relative position is due to the arrangement of the work piece from 04:00 to 10:00 o'clock. For this position there are two examples provided (one steel sheet and one pipe section and two pipe sections). This welding position is similar to the ASME position 6Gu and 5Fu.			

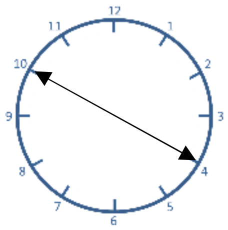
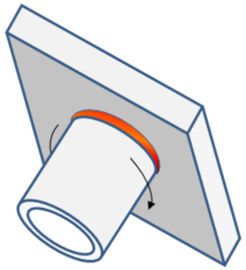
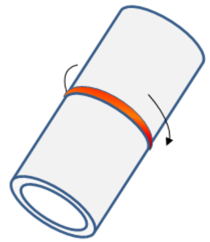
J- L045	J-L045 is the welding position where the seam is welded circular at 0° from the top side of the work piece in direction downwards (falling) left and right side from the pipe. In addition to that the work piece itself is arranged with an angle of 45° to the work bench or to the ground floor. Thereby either pipe and sheet or two pipe sections are connected. The relative position is due to the arrangement of the work piece from 10:00 to 04:00 o'clock. For this position there are two examples provided (one steel sheet and one pipe section and two pipe sections). This welding position is similar to the ASME position 5Gd and 5Fd.			

Figure 171: sketches welding current – welding positions H-L045 and J-L045

Weldseams:

Some of the established welding seams (like square butt weld, single-V butt weld, single-Y seam, double-V butt weld, single-U butt weld, double-U butt weld, hollow weld) are shown and declared by corresponding sketches for revision purposes.

Designation	Sketch	Measures
square butt weld		one side 3 to 8 mm both sides <8 mm
hollow weld (single)		one side >2 mm
hollow weld (double)		both sides >2 mm

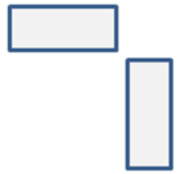
Designation	Sketch	Measures
single-Y seam		one side 5 to 40 mm with backing run >10 mm
hollow weld (corner)		one side >2 mm both sides >3 mm
hollow weld (overlap)		one side >2 mm

Figure 172: sketches welding current – welding seams Table A

Designation	Sketch	Measures
single-V butt weld (both)		one side 3 to 10 mm with backing run 3 to 40 mm
double-V butt weld		both sides >10 mm
single-U butt weld		one side >12 mm with backing run >12 mm

Designation	Sketch	Measures
single-V butt weld (one)		one side 3 to 10 mm with backing run 3 to 30 mm
double-V butt weld (spread)		both sides >10 mm
double-U butt weld		both sides >12 mm

Figure 173: sketches welding current – welding seams Table B

Be aware that also combinations of welding seams are possible. One example is single-V but weld (one), which is a combination of square butt weld and V butt weld.

Welding electrode types: for unalloyed steel electrodes

Welding electrodes need to have different properties for different use cases. This is why there are different types of electrodes existing. The properties can be identified via the electrode designation. The corresponding selections are provided according to the possible designations for revision purposes. The designation for welding electrodes starts with the big letter “E”. Further there are six subdivisions containing different information. The program provides *ComboBoxes* with six different selections containing corresponding items. The result will be displayed accordingly. The program provides the designations for unalloyed steel electrodes.

E	46	3	B	4	2	H5
	Selection 1	Selection 2	Selection 3	Selection 4	Selection 5	Selection 6

Selection 1:

This selection has two characters. The selection results three different output variables. These are the yield stress, the tenacity as a range and the percentage value for the elongation. The following items are provided:

- 35,
- 38,
- 42,
- 46,
- 50.

Selection 2:

This selection has one character. The selection results the temperature for the notch impact energy of 47 Joule. The following items are provided:

- Z,
- A,
- 0 to 6.

Selection 3:

This selection can have one or two characters. The selection results the type of covering in which the electrode is embedded. The following items are provided:

- A,
- C,
- R,
- RR,
- RC,
- RA,
- RB,
- B.

Selection 4:

This selection has one character. The selection results two different output variables. The first is the percentage value of the turnout for the electrode and the second is the relevant type of current (AC / DC). The following items are provided:

- 1 or 2,
- 3 or 4,
- 5 or 6,
- 7 or 8.

Thereby each of the number pairs belong to one turnout value for the electrode.

Selection 5:

This selection has one character. The selection results the approved welding positions for the electrode. The following items are provided:

- 1 to 5.

Selection 6:

This selection can have two or three characters. The selection results the content of hydrogen inside the electrode material. The unit is milliliter per 100 gram [ml / 100 g]. The following items are provided:

- H5 (equal 5 ml / 100 g),
- H10 (equal 10 ml / 100 g),
- H15 (equal 15 ml / 100 g).

Table 1: welding currents depending on the electrode diameter

The welding currents are displayed according to the selected electrode diameter. The electrode length and the recommended welding current range for the selected electrode diameter are resulting and can be assumed as a basic setting. Further an empirical formula for the recommended current range is shown.

For the electrode diameter on the left side of the form the following selections are provided:

- 2.0 mm,
- 2.5 mm,
- 3.2 mm,
- 4.0 mm,
- 5.0 mm,
- 6.0 mm.

For the electrode diameter on the right side of the form the following results are displayed:

- use minimum current,
- use average current,
- use maximum current,
- electrode diameter,
- electrode length,
- current range,
- empirical formula,
- base current,
- factor,
- new current.

Table 2: welding currents depending on the wall thickness

The welding currents are displayed according to the selected wall thickness. It is the wall thickness of the steel pipe that should be welded. The selection is divided up in root, hotpass, middle bead and top bead. The basic values are provided for a single-V but weld, the welding position PG and the electrode covering type C. The data in brackets are information for the welding position and the electrode covering which refer to the stored basic values. In case if factors have been determined for other electrodes, this data can be disregarded.

For the wall thickness on the left side of the form the following selections are provided:

- 8 mm root (PG/C),
- 8 mm hotpass (PG/C),
- 8 mm middle bead (PG/C),
- 8 mm top bead (PG/C),
- 10 mm root (PG/C),
- 10 mm hotpass (PG/C),
- 10 mm middle bead (PG/C),
- 10 mm top bead (PG/C),
- 12 mm root (PG/C),
- 12 mm hotpass (PG/C),
- 12 mm middle bead (PG/C),
- 12 mm top bead (PG/C).

For the wall thickness on the right side of the form the following results are displayed:

- wall thickness,
- position,
- weldseam,
- electrode type,
- electrode diameter,
- base current,
- factor,
- new current.

Table 3: welding currents depending on the measure “a”

The welding currents are displayed according to the selected measure “a”. The measure “a” is a value for the thickness of the weldseam. The basic values are provided for a hollow seam (T), the welding positions PG, PB or PF and electrode types RC, RR, RR160, B. The data in brackets are information for the welding position and the electrode covering which refer to the stored basic values. In case if factors have been determined for other electrodes, this data can be disregarded.

For the measure “a” on the left side of the form the following selections are provided:

- 2 mm (PA/RC),
- 3 mm (PB/RR),
- 4 mm (PB/RR),
- 4 mm (PB/RR160),
- 5 mm root(PB/RR),
- 5 mm top bead (PB/RR),
- 6 mm (PB/RR160),
- 6 mm root (PB/RR),
- 6 mm top bead (PB/RR),
- 6 mm (PB/RR),
- 8 mm root (PF/B),
- 8 mm top bead (PF/B).

For the measure “a” on the right side of the form the following results are displayed:

- measure "a",
- position,
- weldseam,
- electrode type,
- electrode diameter,
- base current,
- factor,
- new current.

Table 4: welding currents depending on the plate thickness

The welding currents are displayed according to the selected plate thickness. It is the thickness of the steel sheet or steel plate that should be welded. The basic values are provided for a single-V but weld, the welding positions PA or PF and the electrode types RA, RB, B. The data in brackets are information for the welding position and the electrode covering which refer to the stored basic values. In case if factors have been determined for other electrodes, this data can be disregarded.

For the plate thickness on the left side of the form the following selections are provided:

- 4 mm (PA/RA),
- 6 mm root (PA/RA),
- 6 mm top bead (PA/RA),
- 10 mm root (PA/B),
- 10 mm top bead (PA/B),
- 10 mm root (PF/RB),
- 10 mm top bead (PF/RB),
- 15 mm root (PA/B),
- 15 mm top bead (PA/B),
- 15 mm root (PF/B),
- 15 mm top bead (PF/B),
- 20 mm root (PA/B),
- 20 mm top bead (PA/B),
- 20 mm root (PF/B),
- 20 mm top bead (PF/B).

For the plate thickness on the right side of the form the following results are displayed:

- plate thickness,
- position,
- weldseam,
- electrode type,
- electrode diameter,
- base current,
- factor,
- new current.

Table 5: user defined data sets

This table offers the possibility to enter, save and restore user defined data sets. Therefore eight different *TextBoxes* are provided for the data input. Accordingly there are eight criteria that can be defined. On the left side a *ListBox* displays the already stored data sets. One of the data sets can be selected and it will be called by clicking the calculate button afterwards. This is at least very similar to the function that is provided for loading the stored values.

For the user defined data on the right side of the *ListBox* the following criteria are provided:

- measure,
- position,
- weldseam,
- electrode type,
- electrode diameter,
- base current,
- factor,
- new current.

By clicking the button below the *ListBox* the list of actual stored user defined value sets can be refreshed. In order to display all the latest data stets this button should be clicked after a new data set was stored.

In order to enter new data the *TextBoxes* have to be unlocked first. This is done via the button with the small open lock symbol. The *TextBoxes* can be locked again via the button with the small close lock symbol. In case if the *TextBoxes* are locked, they have a control-colored background (light gray). In case if the *TextBoxes* are unlocked, they have an info-colored background (light yellow). Only in this case they are editable. The info-colored background (light yellow) indicates that the data are free user definable. That means that there are no internal routines provided checking the entered data. It should be taken care that the values are not overwritten accidentally.

All values are displayed according to the stored user defined data sets. Be aware that the defined values are only textual information and that there are no rules defined regarding the input philosophy. Attention: for this table also the current by factor calculation will not be carried out!

11.5.2. Variables (What are the input and output values? What are their limits?)

electrode diameter (Table 1-5)

It is the diameter of the considered welding electrode. The variable is entered by selection.

The variable type is Selection.
The unit is millimeter [mm].
The minimum limit is 2 mm.
The maximum limit is 6 mm.
The variable has no replacement value.
The number of digits is 4.

current range (Table 1)

It is recommended welding current range for the selected electrode diameter. Be aware that this value is to be assumed as a basic setting. The real proper current has to be adjusted in practice.

The variable type is Output.
The unit is ampere [A].
There is no defined minimum limit for output variables.
There is no defined maximum limit for output variables.
There is no defined replacement value for output variables.
There is no defined number of digits for output variables.

electrode length (Table 1)

It is the established length of the considered welding electrode as it can usually be ordered.

The variable type is Output.
The unit is millimeter [mm].
There is no defined minimum limit for output variables.
There is no defined maximum limit for output variables.
There is no defined replacement value for output variables.
There is no defined number of digits for output variables.

empirical formula (Table 1)

It is an empirical formula for the recommended current range. Be aware that this value is to be assumed as a basic setting. The real proper current has to be adjusted in practice.

The variable type is Output.
The variable has no unit [-].
There is no defined minimum limit for output variables.
There is no defined maximum limit for output variables.
There is no defined replacement value for output variables.
There is no defined number of digits for output variables.

wall thickness (Table 2, 5)

It is the wall thickness of the steel pipe that should be welded. The variable is entered by selection. The selection is divided up in root, hotpass, middle bead and top bead.

The variable type is Selection.
The unit is millimeter [mm].
The minimum limit is 8 mm.
The maximum limit is 12 mm.
The variable has no replacement value.
The variable has no fix number of digits.

plate thickness (Table 4, 5)

It is the plate thickness of the steel sheet or steel plate that should be welded. The variable is entered by selection. The selection is divided up in root, top bead and fill- and top bead.

The variable type is Selection.
The unit is millimeter [mm].
The minimum limit is 4 mm.
The maximum limit is 20 mm.
The variable has no replacement value.
The variable has no fix number of digits.

measure “a” (Table 3, 5)

It is the measure “a” for the focused welding. The variable is entered by selection. The selection is divided up in RR, R160, root and top bead.

The variable type is Selection.
The unit is millimeter [mm].
The minimum limit is 2 mm.
The maximum limit is 8 mm.
The variable has no replacement value.
The variable has no fix number of digits.

position (Table 2-5)

It is the recommended welding position for the selected item. The EN rules define the positions PA, PB, PC, PD, PE, PF, PG, PH, PJ, PK, H-L045 and J-L045. The ASME Code Section IX defines similar positions. Thereby it is divided up into butt weld (1G, 2G, 3Gu, 3Gd, 4G, 5Gu, 5Gd, 6Gu, 6Gd) and hollow weld (1F, 1FR, 2F, 2FR, 4F, 5Fd, 5Fu).

The variable type is Output.
The variable has no unit [-].
There is no defined minimum limit for output variables.
There is no defined maximum limit for output variables.
There is no defined replacement value for output variables.
There is no defined number of digits for output variables.

weldseam (Table 2-5)

It is the type of the welding seam. Some of the established welding seams are square butt weld, single-V but weld, single-Y seam, double-V butt weld, single-U butt weld, hollow weld.

The variable type is Output.
The variable has no unit [-].
There is no defined minimum limit for output variables.
There is no defined maximum limit for output variables.
There is no defined replacement value for output variables.
There is no defined number of digits for output variables.

electrode diameter (Table 2-5)

It is the electrode diameter that is recommended according to the selection. Be aware that this value is to be assumed as a basic setting. The real proper electrode diameter can deviate from this recommendation.

The variable type is Output.
The unit is millimeter [mm].
There is no defined minimum limit for output variables.
There is no defined maximum limit for output variables.
There is no defined replacement value for output variables.
There is no defined number of digits for output variables.

electrode type (Table 2-5)

It is the electrode type that is recommended according to the selection. Be aware that this value is to be assumed as a basic setting.

The variable type is Output.
The variable has no unit [-].
There is no defined minimum limit for output variables.
There is no defined maximum limit for output variables.
There is no defined replacement value for output variables.
There is no defined number of digits for output variables.

base current (Table 1-5)

It is the welding current that is recommended according to the selection. Be aware that this value is to be assumed as a basic setting. The real proper current has to be adjusted in practice.

The variable type is Output.
The unit is ampere [A].
There is no defined minimum limit for output variables.
There is no defined maximum limit for output variables.
There is no defined replacement value for output variables.
There is no defined number of digits for output variables.

factor (Table 1-5)

It is the factor that is determined by practical tests and the current adjustment for a proper welding process. The factor is the relation between the recommended base current and the new determined welding current. The factor multiplied by the base current results the new current.

The variable type is Input.
The variable has no unit [-].
The minimum limit is 0.01.
The maximum limit is 99.9.
The replacement value is 1.
The number of digits is 6.

new current (Table 1-5)

It is the new current that is determined by practical tests for a proper welding process. The factor is the relation between the recommended base current and the new determined welding current. The factor multiplied by the base current results the new current.

The variable type is Output.
The unit is ampere [A].
There is no defined minimum limit for output variables.
There is no defined maximum limit for output variables.
There is no defined replacement value for output variables.
There is no defined number of digits for output variables.

11.5.3. Operation (How can it be used? How to proceed?)

Step 1:
Select the subprogram
I can choose between seven different subprograms. There are two possibilities for the selection: by clicking the corresponding button or by clicking the corresponding *TabPage*. On the right side there are explanations shown for each of the subprograms. this should give a first orientation.

Regarding the steps the first four *TabPages* are considered as one sequence including seven steps. The steps for the remaining Tables are different.

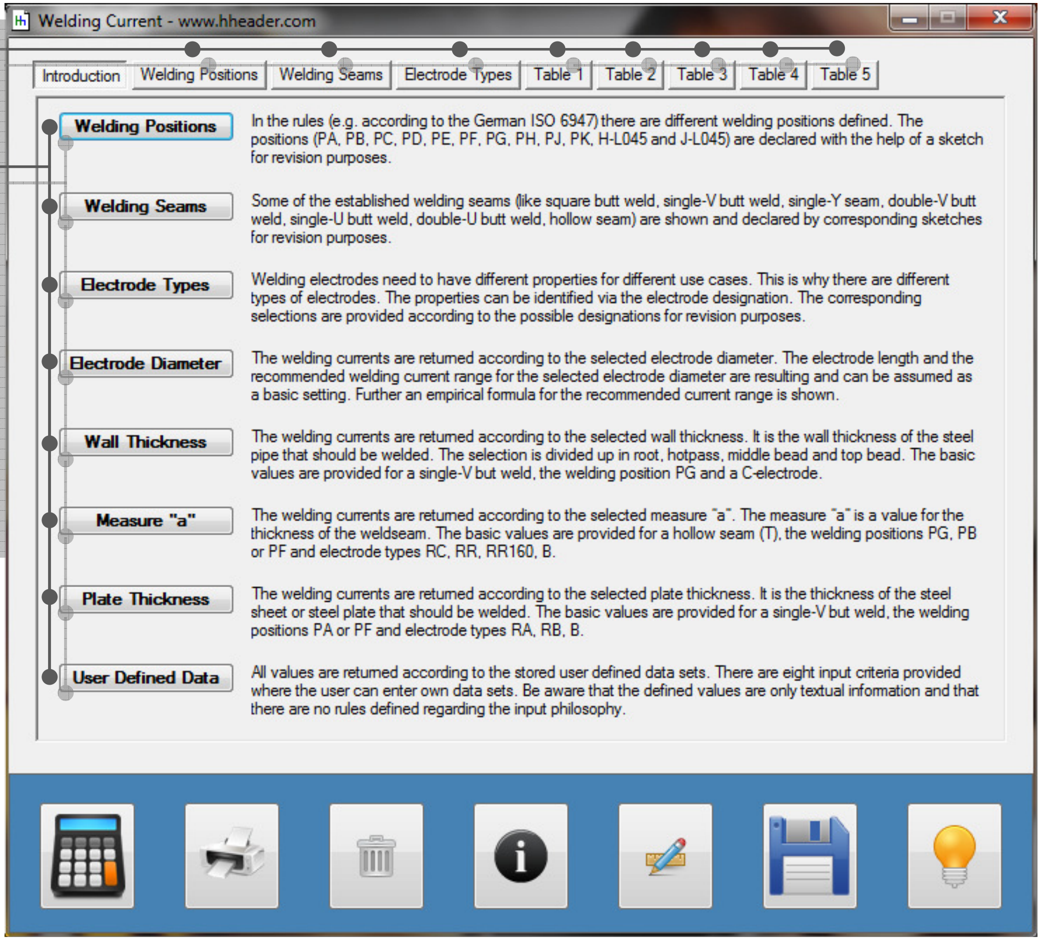


Figure 174: form welding current – introduction

Step 2:
Select the welding position
I can select one of the provided welding positions by clicking the corresponding button. Twelve basic positions can be displayed.

These are:
- PA,
- PB,
- PC,
- PD,
- PE,
- PF,
- PG,
- PH,
- PJ,
- PK,
- H-L045,
- J-L045.

For each welding position there are always two examples displayed at a time. The first on the left is showing a combination of either two steel sheets or one steel sheet and one pipe section. The second example on the right shows either a pipe section or a combination of two pipe sections. Below the sketches there is a description shown for the corresponding welding position.

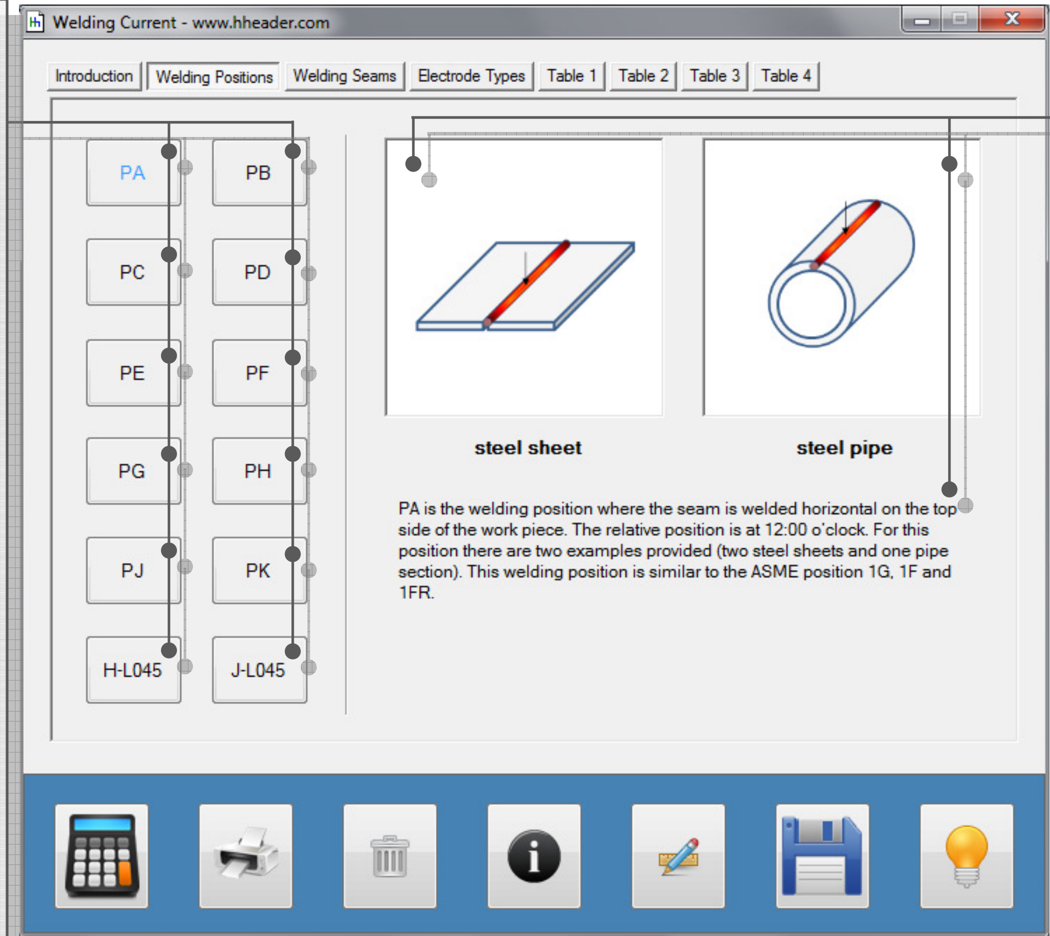


Figure 175: form welding current – welding positions

Step 3:
Check the results
After executing a selection I can check the results. Twelve basic positions can be displayed.

These are:
- PA,
- PB,
- PC,
- PD,
- PE,
- PF,
- PG,
- PH,
- PJ,
- PK,
- H-L045,
- J-L045.

For each welding position there are always two examples displayed at a time. The first on the left is showing a combination of either two steel sheets or one steel sheet and one pipe section. The second example on the right shows either a pipe section or a combination of two pipe sections. Below the sketches there is a description shown for the corresponding welding position.

Step 4:
Select the welding seam type
I can browse through the catalogue of the provided welding seam types. It is possible to scroll left or right by clicking the corresponding button. The catalogue contains twelve basic welding seams which can be displayed (two at a time).

These are:
- square butt weld,
- single-Y seam,
- single-V butt weld (both),
- single-V butt weld (one),
- double-V butt weld,
- double-V butt weld (spread),
- hollow weld (corner),
- hollow weld (double),
- hollow weld (overlap),
- hollow weld (single),
- single-U butt weld,
- double-U butt weld.

The designation and the recommended sheet or pipe thickness are shown accordingly. Be aware that also combinations of welding seams are possible. One example is single-V but weld (one), which is a combination of square butt weld and V butt weld.

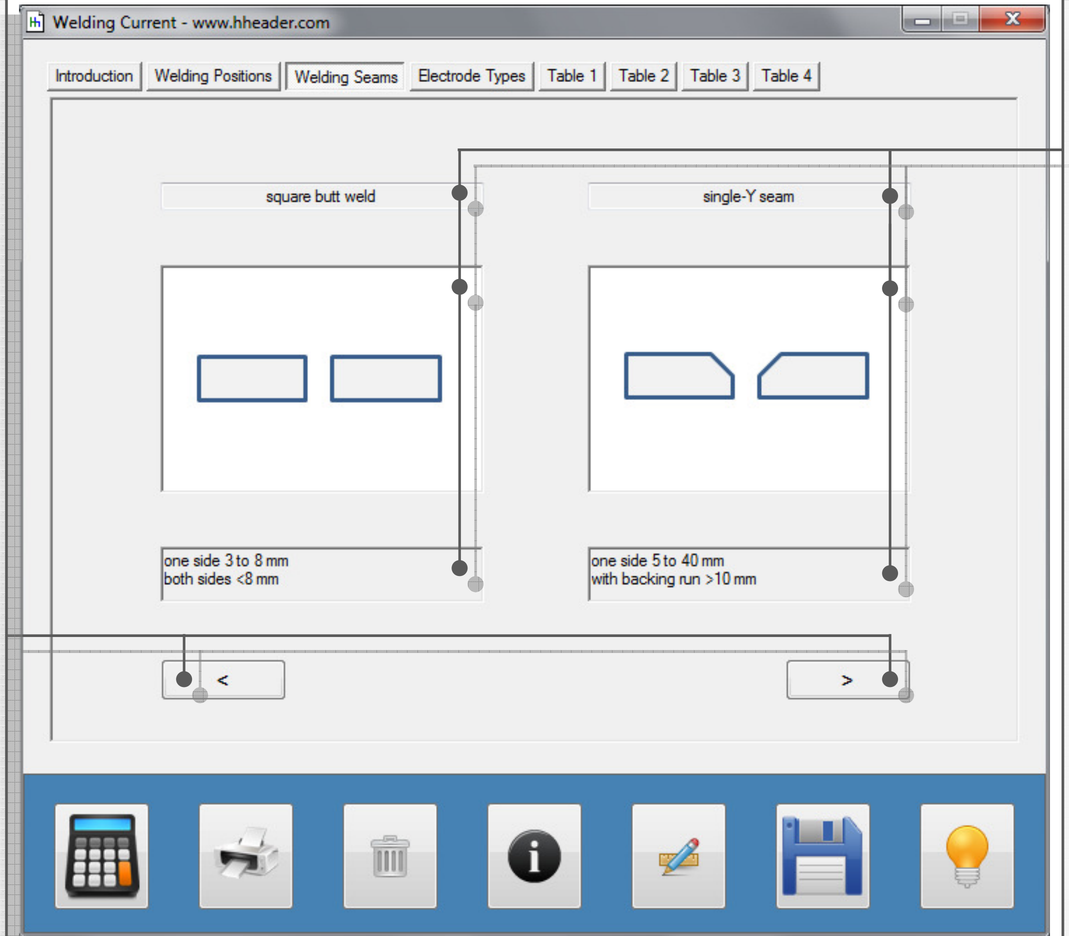


Figure 176: form welding current – welding seams

Step 5:
Check the results
After browsing through the catalogue to the corresponding position I can check the results. A sketch of the welding seam is shown and the designation is displayed above accordingly. Below the sketch the recommended sheet or pipe thickness is displayed. Results are shown (two at a time) for twelve different welding seams.

These are:
- square butt weld,
- single-Y seam,
- single-V butt weld (both),
- single-V butt weld (one),
- double-V butt weld,
- double-V butt weld (spread),
- hollow weld (corner),
- hollow weld (double),
- hollow weld (overlap),
- hollow weld (single),
- single-U butt weld,
- double-U butt weld.

Be aware that also combinations of welding seams are possible. One example is single-V but weld (one), which is a combination of square butt weld and V butt weld.

Step 6:
Select the electrode parameters
I can select the different parameters for the considered welding electrode.

Selection1:
The selection results the yield stress, the tenacity as a range and the percentage value for the elongation.

Selection 2:
The selection results the temperature for the notch impact energy of 47 Joule.

Selection 3:
The selection results the type of covering in which the electrode is embedded.

Selection 4:
The selection results the percentage value of the turnout for the electrode and the relevant type of current.

Selection 5:
The selection results the approved welding positions for the electrode.

Selection 6:
The selection results the content of hydrogen inside the electrode material. The unit is milliliter per 100 gram [ml / 100 g].

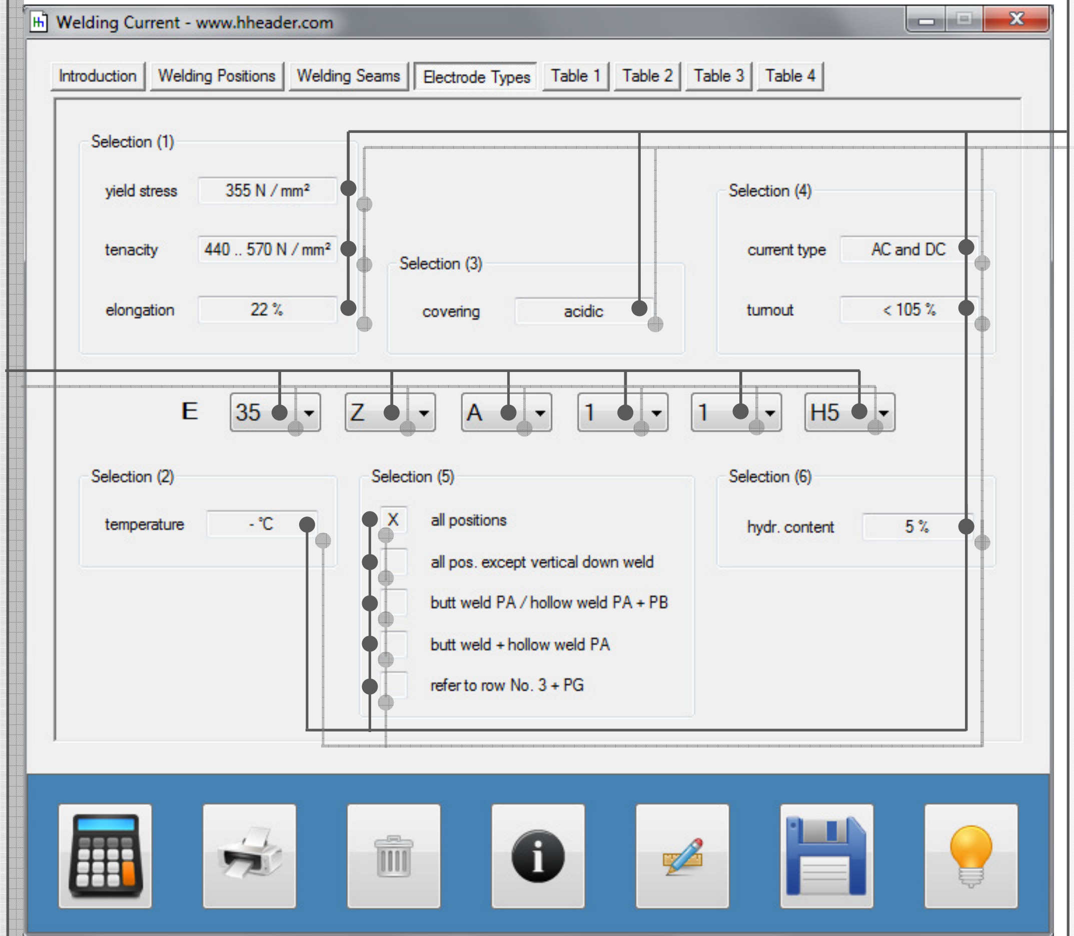


Figure 177: form welding current – electrode types

Step 7:
Check the results
I can check the results according to the executed selections.

Selection 1:
The selection results the yield stress, the tenacity as a range and the percentage value for the elongation.

Selection 2:
The selection results the temperature for the notch impact energy of 47 Joule.

Selection 3:
The selection results the type of covering in which the electrode is embedded.

Selection 4:
The selection results the percentage value of the turnout for the electrode and the relevant type of current.

Selection 5:
The selection results the approved welding positions for the electrode.

Selection 6:
The selection results the content of hydrogen inside the electrode material. The unit is milliliter per 100 gram [ml / 100 g].

Step 1:
Select the electrode diameter
I can select the used electrode diameter in order to get back the corresponding values for electrode length, current range and the empirical formula by that the current range can be roughly calculated.

Step 5:
Fill the Input-*TextBoxes*
I enter the values for the correction factors that have been determined according to practical tests. I should respect the variable limits and take care that the entered values are numeric.

Step 6:
Calculate result
After I entered the input values I can calculate the result. Before the calculation starts, all the input values are checked by an internal routine. Whenever entered values decrease the corresponding min limits or increase the corresponding max limits or are not numeric there will be a message according to the fault. The values will be corrected automatically by the internal routine.

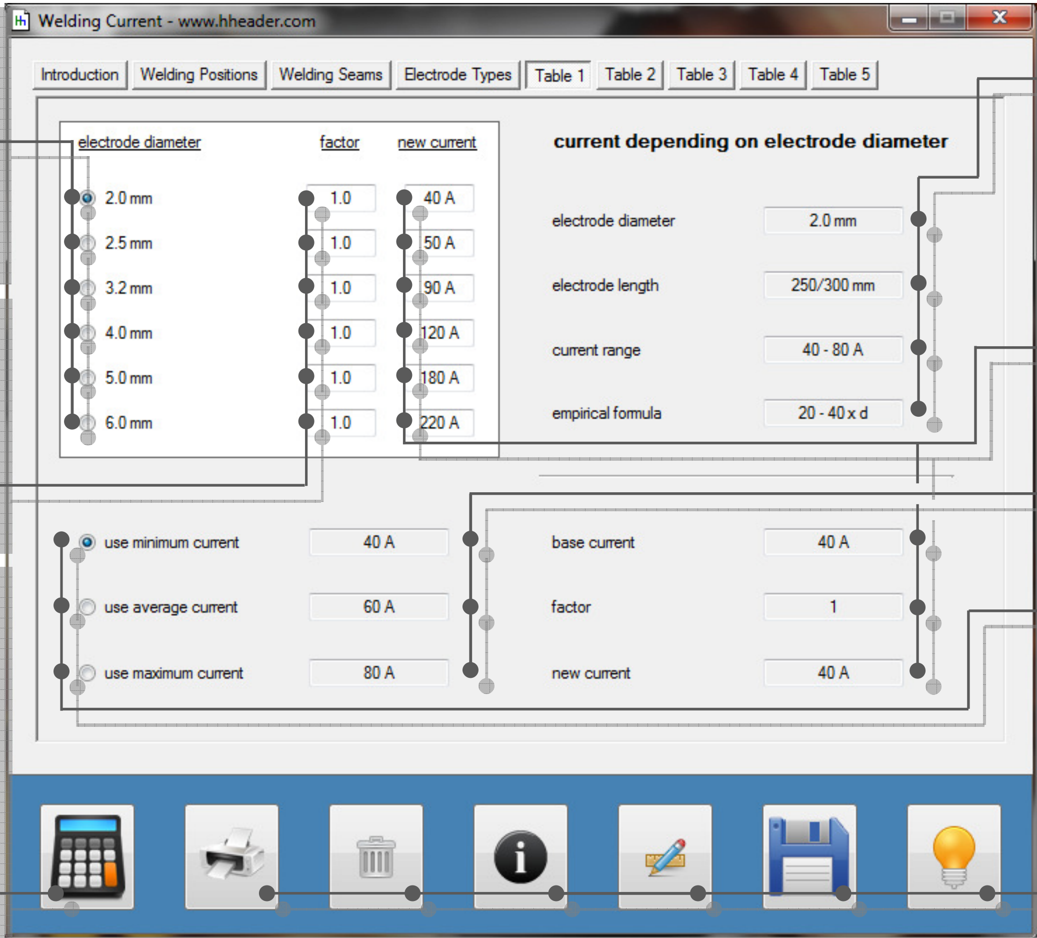


Figure 178: form welding current – electrode diameter

Step 2:
Check result after the first step
After selecting the used electrode diameter I can check the results regarding electrode length, current range and the empirical formula.

Step 7:
Check the new current values
After clicking the Calculate-Button I can check the results for the new current values.

Step 3:
Check the current values
After clicking the Calculate-Button I can check the result for the current values.

Step 4:
Select the used current value
I can select which value should be basis for the factor multiplication.

Step 8:
Further actions
After the calculation I can have the following options: Print Data, Erase Data, Program Information, Notes, Save or Restore Values. While printing a new calculation is done automatically. Clicking the Erase-Button will empty all the *TextBoxes* at once.

Step 1:
Select the electrode diameter
I can select the used electrode diameter in order to get back the corresponding values for electrode length, current range and the empirical formula by that the current range can be roughly calculated.

Step 3:
Fill the Input-*TextBoxes*
I enter the values for the correction factors that have been determined according to practical tests. I should respect the variable limits and take care that the entered values are numeric.

Step 4:
Calculate result
After I entered the input values I can calculate the result. Before the calculation starts, all the input values are checked by an internal routine. Whenever entered values decrease the corresponding min limits or increase the corresponding max limits or are not numeric there will be a message according to the fault. The values will be corrected automatically by the internal routine.

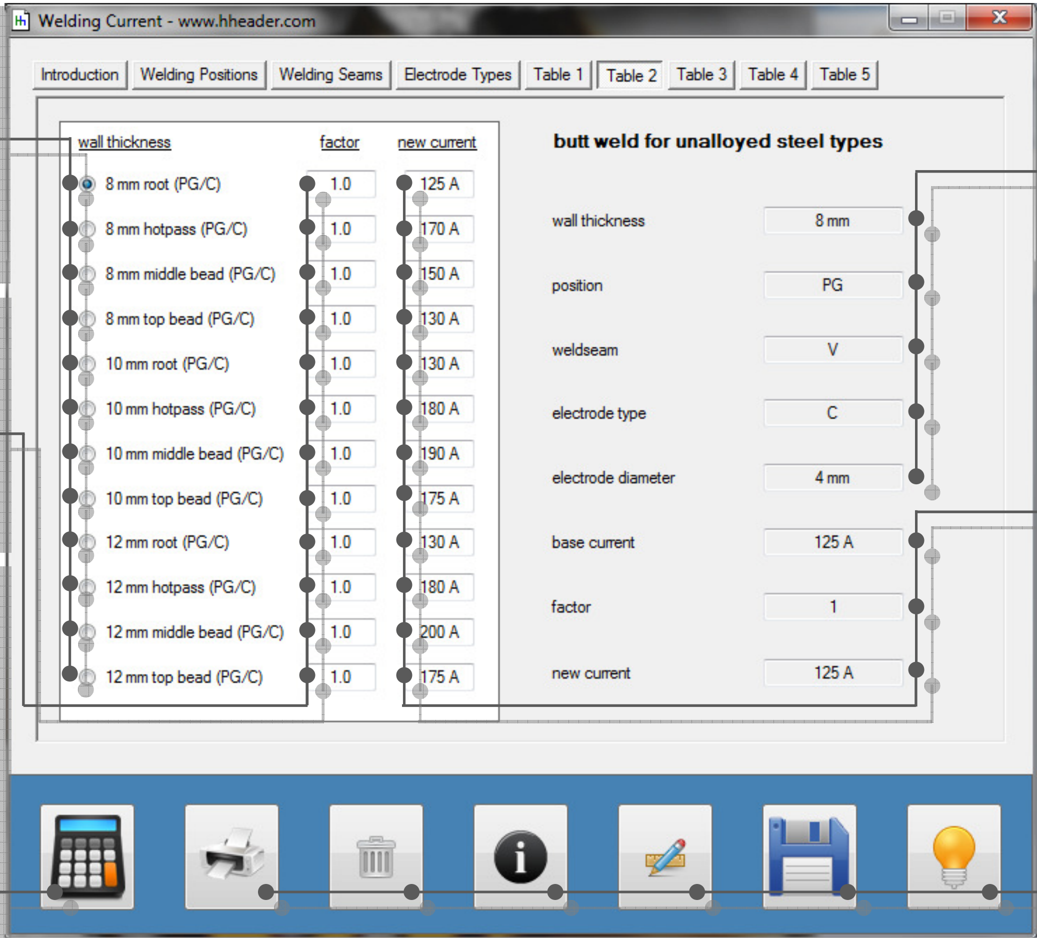


Figure 179: form welding current – wall thickness

Step 2:
Check result after the first step
After selecting the used electrode diameter I can check the results regarding electrode length, current range and the empirical formula.

Step 5:
Check the new current values
After clicking the Calculate-Button I can check the results for the new current values.

Step 6:
Further actions
After the calculation I can have the following options: Print Data, Erase Data, Program Information, Notes, Save or Restore Values. While printing a new calculation is done automatically. Clicking the Erase-Button will empty all the *TextBoxes* at once.

Step 1:
Select the electrode diameter
I can select the used electrode diameter in order to get back the corresponding values for electrode length, current range and the empirical formula by that the current range can be roughly calculated.

Step 3:
Fill the Input-*TextBoxes*
I enter the values for the correction factors that have been determined according to practical tests. I should respect the variable limits and take care that the entered values are numeric.

Step 4:
Calculate result
After I entered the input values I can calculate the result. Before the calculation starts, all the input values are checked by an internal routine. Whenever entered values decrease the corresponding min limits or increase the corresponding max limits or are not numeric there will be a message according to the fault. The values will be corrected automatically by the internal routine.

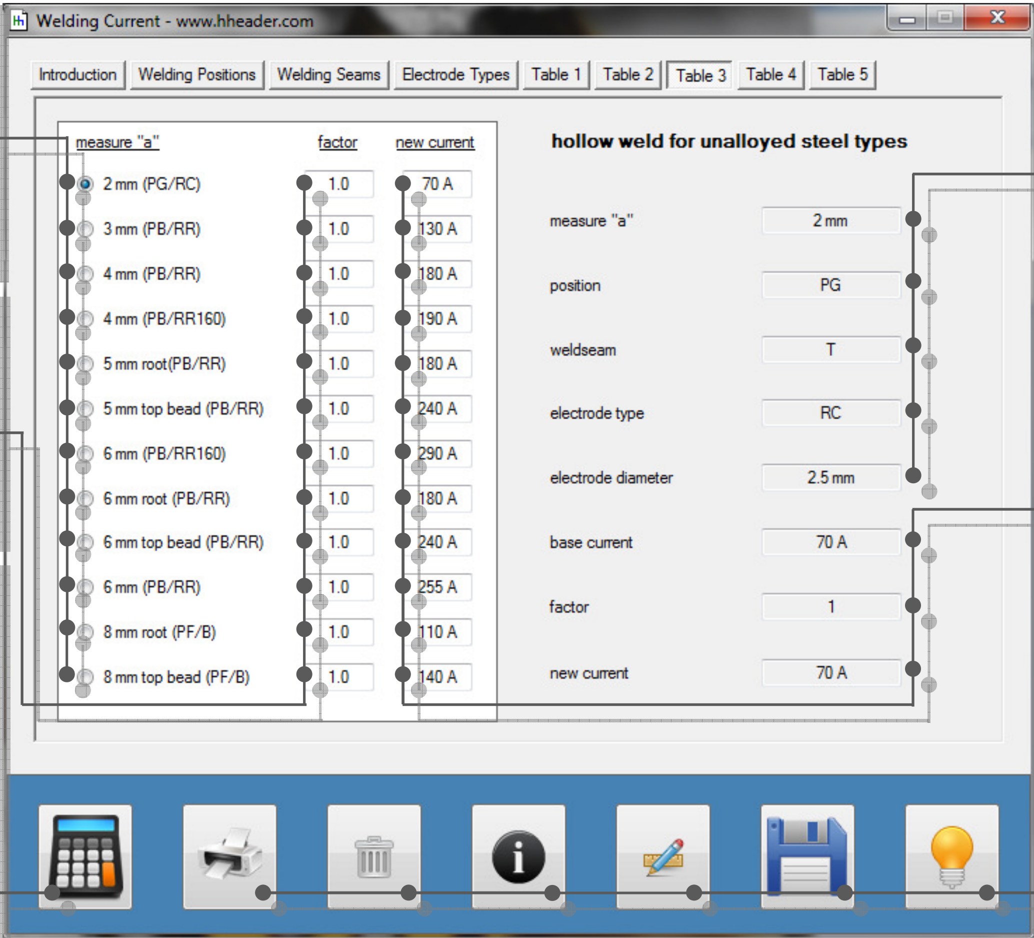


Figure 180: form welding current – a measure

Step 2:
Check result after the first step
After selecting the used electrode diameter I can check the results regarding electrode length, current range and the empirical formula.

Step 5:
Check the new current values
After clicking the Calculate-Button I can check the results for the new current values.

Step 6:
Further actions
After the calculation I can have the following options: Print Data, Erase Data, Program Information, Notes, Save or Restore Values. While printing a new calculation is done automatically. Clicking the Erase-Button will empty all the *TextBoxes* at once.

Step 1:
Select the electrode diameter
I can select the used electrode diameter in order to get back the corresponding values for electrode length, current range and the empirical formula by that the current range can be roughly calculated.

Step 3:
Fill the Input-*TextBoxes*
I enter the values for the correction factors that have been determined according to practical tests. I should respect the variable limits and take care that the entered values are numeric.

Step 4:
Calculate result
After I entered the input values I can calculate the result. Before the calculation starts, all the input values are checked by an internal routine. Whenever entered values decrease the corresponding min limits or increase the corresponding max limits or are not numeric there will be a message according to the fault. The values will be corrected automatically by the internal routine.

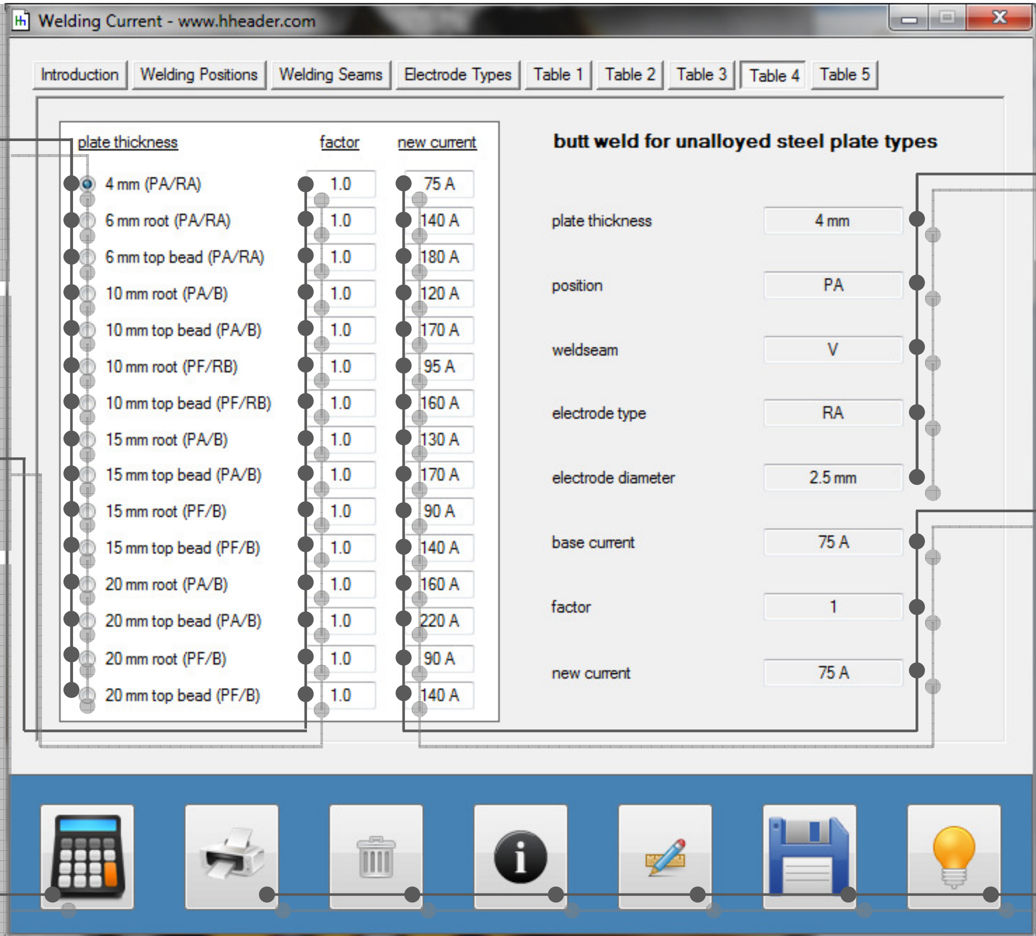


Figure 181: form welding current – plate thickness

Step 2:
Check result after the first step
After selecting the used electrode diameter I can check the results regarding electrode length, current range and the empirical formula.

Step 5:
Check the new current values
After clicking the Calculate-Button I can check the results for the new current values.

Step 6:
Further actions
After the calculation I can have the following options: Print Data, Erase Data, Program Information, Notes, Save or Restore Values. While printing a new calculation is done automatically. Clicking the Erase-Button will empty all the *TextBoxes* at once.

Step 2:
Select a file
I can select an already stored file with the used defined data from the list.

Step 1:
Refresh the file list
I can refresh the file list by clicking the button below the *ListBox*.

Step 6:
Fill the Input-*TextBoxes*
I enter the values for the correction factors that have been determined according to practical tests. I should respect the variable limits and take care that the entered values are numeric.

Step 3:
Calculate result
Clicking the Calculate-Button in this case will start loading the selected file. The results will be displayed in the *TextBoxes* on the right side accordingly. The defined values are only textual information. There are no rules defined regarding the input philosophy. Attention: for this table also the current by factor calculation will not be carried out!

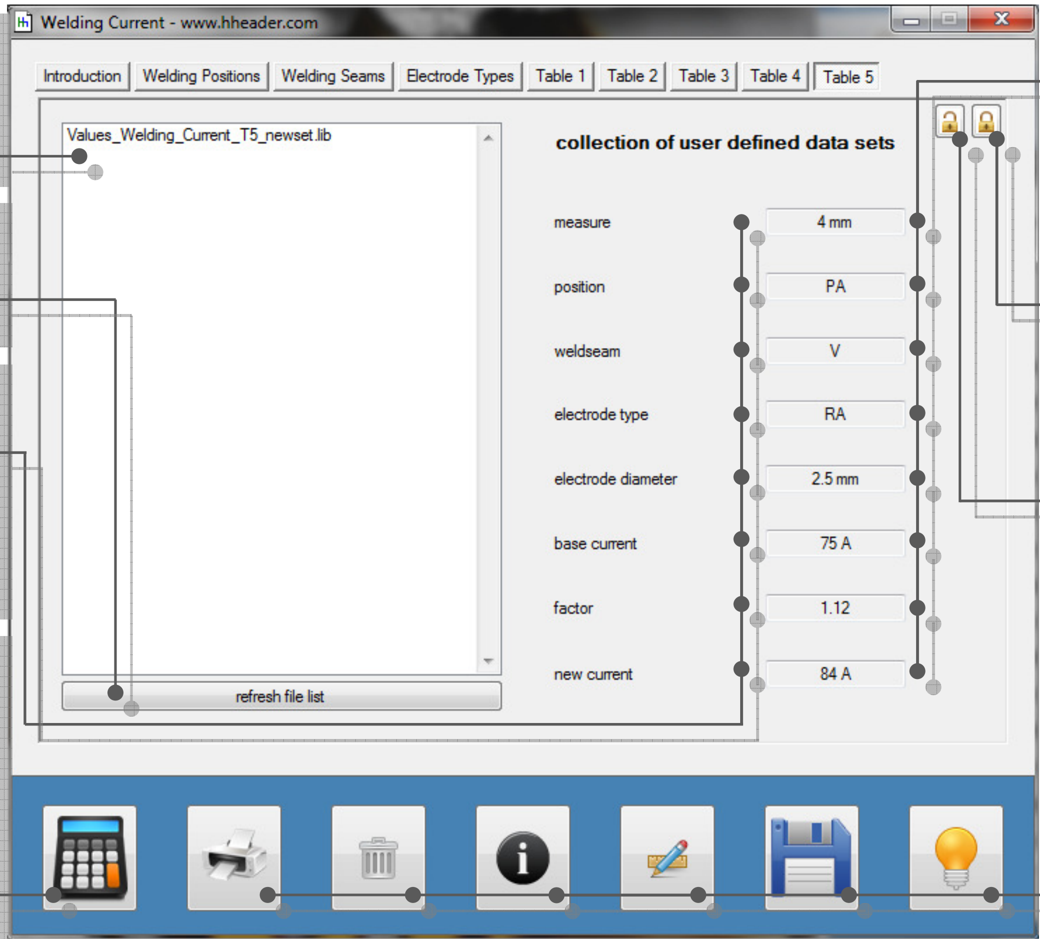


Figure 182: form welding current – user defined data

Step 4:
Check result after loading
After loading the file I can check the results regarding the provided criteria.

Step 5: (option)
Unlock the *TextBoxes*
In case if I like to change the data I have to unlock the *TextBoxes* first. The back color of the *TextBoxes* will change to the known color “Info”.

Step 7: (option)
Lock the *TextBoxes*
After changing the values the textboxes should be locked again. The back color of the *TextBoxes* will change to the known color “Control”.

Step 8:
Further actions
After the calculation I can have the following options: Print Data, Erase Data, Program Information, Notes, Save or Restore Values. While printing a new calculation is done automatically. Clicking the Erase-Button will empty all the *TextBoxes* at once.

11.6. MTBF – Mean Time Between Failures

11.6.1. Purpose (What can it be used for? What can it not be used for?)

The program is part of category 6 – mechanics. The “Mean Time Between Failures” (MTBF) is the average time that elapses from one significant failure to the next significant failure of an operated system or device. It is obvious that the mentioned failures are predictable failures. A significant failure in this case means a fault or error effectuating the system or device massively, so that it cannot be fully operated with its designated functionality anymore. Especially for single engineered system the MTBF can be an interesting value. It is also not too rare that the customer or contractor demands different calculations regarding the MTBF in order to get an overview about the availability of the installed system. In combination with this it is important which parts or compounds are the weak points of the system and what is the required effort as time and work to repair the system and get it ready for operation again. For the evaluation of a complete system all the installed parts have to be regarded individually. Therefore it does not play a rule if the parts are mechanical, electrical, hydraulic or pneumatic operated. It is recommended to fill all the relevant parts with the relevant information in a table.

For some devices the MTBF cannot be determined directly as a time, but indirectly via other given values (the number of switching cycles for example) and further considerations. For example: supposed a relay has a life time of 100000 switching cycles. It is further supposed that the relay is switched around 33 times a day under normal operation circumstances. So a failure can be predicted or at least be assumed to happen after 100000 / 33 days which is more than 8 years. The following table shows some examples. The values are just assumed. The table is a recommendation how the data can be displayed in order to get an overview about the MTBF and with it about the availability of the plant.

No.	Device	Type	Manufacturer	Drive	Life Time	Rate	Grade	Unit Factor	MTBF	MTTR
1	Relay	ABC 123	Company A	E	100000 cycles	3 cycles / h	12 h / d	365.25 d / year	8 years	1 h
2	Pump	DEF 456	Company B	E	3500000 m^3	150 m^3 / h	14 h / d	365.25 d / year	5 years	8 h
3	Blower	GHI 789	Company C	E	200000000 m^3	17000 m^3 / h	16 h / d	365.25 d / year	2 years	8 h
4	Transformer	JKL 101	Company D	E	38000 h	1	24 h / d	365.25 d / year	4 years	1 h
5	Buffer Amplifier	MNO 112	Company E	E	29000 h	1	24 h / d	365.25 d / year	3 years	1 h
6	Frequency Converter	PQR 131	Company F	E	60000 h	1	14 h / d	365.25 d / year	12 years	4 h
7	Valve	STU 415	Company G	P	55000 cycles	2 cycles / h	16 h / d	365.25 d / year	5 years	4 h
8	PLC-Compound	VWX161	Company H	E	5 years	1	24 h / d	365.25 d / year	5 years	2 h
9	Hydraulic Cylinder	Y&Z 718	Company I	H	12500 cycles	0.5 cycles / h	24 h / d	365.25 d / year	3 years	2 h

Figure 183: table for MTBF-data-recording

The MTBF can be calculated by dividing the life time value by the product of rate and grade and the unit factor, which is at least the degree of capacity utilization. Therefore it is mandatory that the correct time units have to be considered as corresponding factors! For the table on the previous page the factor for the time unit is 365.25 d / year in order to get years as unit for the MBTF.

The life time value defines either the predicted total operation time or the predicted total amount of units the device can reach until it is damaged or it is required for maintenance or overhaul. The rate is a value for the performance of the device. The grade is a value for utilization of the device. The unit factor has to be chosen according to the displayed time unit for the MTFB. Rate, grate and the unit factor have to be multiplied first. The life time value has to be divided by the result and this gives back the MTBF.

The MTTR which is the abbreviation for “Mean Time To Recover” or “Mean Time To Repair” declares the assumed time that it takes to fix the fault. Be aware that this will define the availability of the device and further probably also the availability of a total plant. It is important to decrease the MTTR as far as possible to avoid unnecessary long term shutdowns. This can be mainly reached by holding the proper spare parts in stock, because generally it goes faster to replace a defective part than repairing it on site. Beyond this defective parts can often not be repaired or it is not economic to repair them.

Values that are similar to the MTBF are:

- Mean Cycles Between Failure (MCBF),
- Mean Distance Between Failure (MDBF),
- Mean Time Between Critical Failure (MTBCF),
- Mean Time Between Maintenance (MTBM),
- Mean Time Between Overhaul (MTBO),
- Mean Time Between Unscheduled Removal (MTBUR),
- Mean Time To Failure (MTTF).

Typical units for the Mean Times are:

- hours = 60 minutes = 3600 seconds,
- days = 24 hours = 1440 min,
- months = 30.4375 days = 730.5 hours,
- years = 365.25 days = 8766 hours,
- FIT^-1 = 114077.12 years = 10^9 hours.

FIT (Failure in Time) is the amount of outages that occur during an operation time of 10^9 hours = 114077.12 years.

At least it is important to avoid unnecessary shutdowns in the first. If possible shutdowns should be done scheduled, only. Therefore it is required to plan and carry out a proper maintenance schedule. If a shutdown occurs according to a fault, the outage should be as short as possible. Therefore it is required to hold proper selected spare parts in stock.

The term “Device” is here used as a generic term. Regarding the considerations it can be many different things like an aggregate, an element, an instrument, a plant compound or also a complete plant etc., of course. In practice it has to be considered that a system can consist of more than one device. This affects the MTBF and the availability of the system. Generally devices can be arranged in serial or in parallel. A block diagram for these two cases is shown in the table below. The program also provides these two possibilities.

Parallel arrangement:

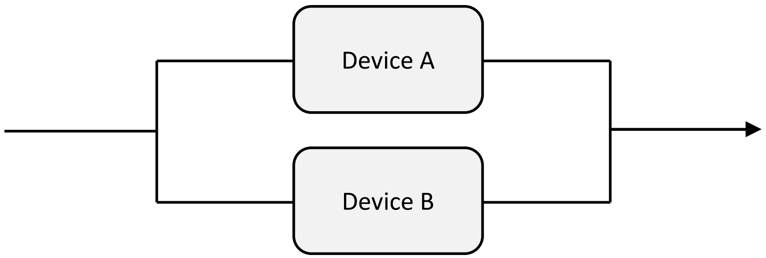


Figure 184: Device A and B in parallel

Supposed that two parallel devices are redundant (e.g. two pump stations or two redundant filters), the MTBF will be increased. If one device has a fault, the other device can take over until the fault is fixed respectively the maintenance works are finished.

Serial arrangement:

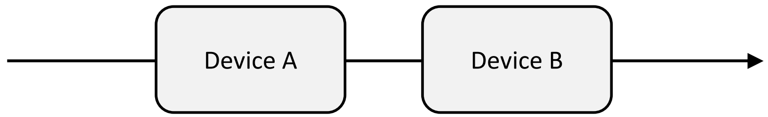


Figure 185: Device A and B in serial

For many processes a serial combination of devices is required (e.g. for a demineralization street, where an anionic and cationic ion-exchanger is required to be operated in one line). For a serial combination the MTBF will be decreased. If one device has a fault, the system will be out of operation until the fault is fixed respectively the maintenance works are finished.

The program considers a combined MTTR of the compounds Device A and Device B for the combined systems. Be aware that only a parallel redundancy can extend the MTBF and the availability. In case if a certain total MTBF respectively a certain availability is demanded and cannot be reached by one device, there is generally the option of a parallel arrangement. Also two serial arranged compounds can be built up redundant, if required. In this case a calculation can be carried out for the serial combined system in the first. Afterwards the same result can be iterated for Device A and Device B in order to get the resulting values for the parallel combination of the two serial arranged systems. Of course, the iteration procedure can be repeated several times.

It is obvious that the expenses for redundant systems are more than double of the single system. The important questions are: What are the costs of an unnecessary shut down? How often and how long are maintenance works required? What is more economic in the long term?

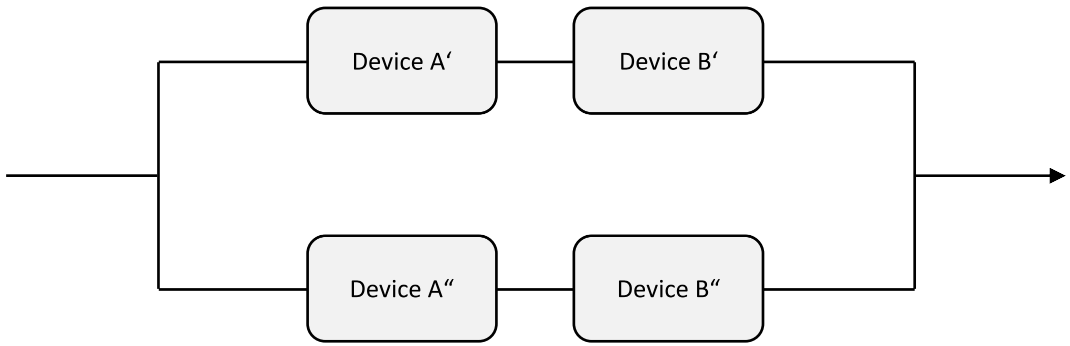


Figure 186: two serial arranged lines with two devices in parallel to each other

The program provides calculations for the MTBF and the availability under consideration of a given MTTR. Values can be entered and results are calculated for Device A, Device B and a selectable combination of the two devices, where they can be arranged in parallel or in serial. So the form is divided up into three parts: Device A in the upper part, Device B in the middle part and the combination of both devices in the lower part. For MTBF and MTTR there are unit selections provided. By corresponding *RadioButtons* it can be selected if Device A, Device B or the combination of devices is defined as an output block. The residual two blocks are input blocks. This refers to the MTBF and the MTTR. The availability is always an output variable.

11.6.2. Variables (What are the input and output values? What are their limits?)

MTBF

It is the “Mean Time Between Failures” for the corresponding device. The MTBF is the average expected operation time between two required maintenance works or repair works.

The variable type is Input.
For this variable a selection of different units is provided:

- hours [hours],
- days [days],
- months [months],
- years [years],
- FIT^-1 [multiple of 10^9 hours].

The minimum limit is 0.0001.
The maximum limit is 99999.
The replacement value is 10.
The number of digits is 10.

FIT (Failure in Time) is the amount of outages that occur during an operation time of 10^9 hours = 114077.12 years.

MTTR

It is the “Mean Time To Recover” or also “Mean Time To Repair” for the corresponding device. The MTTR is the average expected operation time that is required for the maintenance works or repair works.

The variable type is Input.
For this variable a selection of different units is provided:

- hours [hours],
- days [days],
- months [months],
- years [years],
- FIT^-1 [multiple of 10^9 hours].

The minimum limit is 0.0001.
The maximum limit is 99999.
The replacement value is 10.
The number of digits is 10.

FIT (Failure in Time) is the amount of outages that occur during an operation time of 10^9 hours = 114077.12 years.

Availability

It is the calculated availability of the device. The calculation is based on the given values for MTBF and MTTR.

The variable type is Output.
The unit is percent [%].
There is no defined minimum limit for output variables.
There is no defined maximum limit for output variables.
There is no defined replacement value for output variables.
There is no defined number of digits for output variables.

Designation texts

For each compound, Device A, Device B and the results there are string variables provided that can be used as user defined designations. The variables are provided for the MTBF, the MTTR and the Availability.

The variable type is Input.
The variables have no unit [-].
There is no defined minimum limit for string variables.
There is no defined maximum limit for string variables.
There is no defined replacement value for string variables.
The number of digits is 26.

For the combined systems there are four different selections for the connection cases provided (2 x serial and 2 x parallel). The provided selections are:

- Device A and Device B in serial (factor 1.0),
- Device A and Device B in parallel (factor 1.0),
- Device A and Device B in serial (factor 2.0),
- Device A and Device B in parallel (factor 2.0),

The different factors are for the consideration of different combined MTTRs, where the factor 1.0 considers the total MTTR of both devices and the factor 2.0 considers the average MTTR of both devices.

Keep in mind:
For the serial arrangement the MTBF of each single unit (Device A and B) is greater than the MTBF for the combined system.
That means MTBFa > MBTFab and MTBFb > MBTFab.

For the parallel arrangement the MTBF of each single unit (Device A and B) is less than the MTBF for the combined system.
That means MTBFa < MBTFab and MTBFb < MBTFab.

11.6.3. Operation (How can it be used? How to proceed?)

Step 1:
Select the device to be calculated
By clicking on the corresponding *RadioButton* I can choose the device to be calculated.

Step 2: (option)
Assume texts for devices
By checking the *CheckBoxes* the entered texts will be assumed for the device designations for the printing. If the *CheckBox* is unchecked, the designation will be according to the label on the left side.

Step 8:
Check result
After clicking the Calculate-Button I can check the result.

Step 6:
Enter the number of decimal places
I enter the number of decimal places for the output variables.

Step 7:
Calculate result
After I entered the input values I can calculate the result. Before the calculation starts, all the input values are checked by an internal routine.

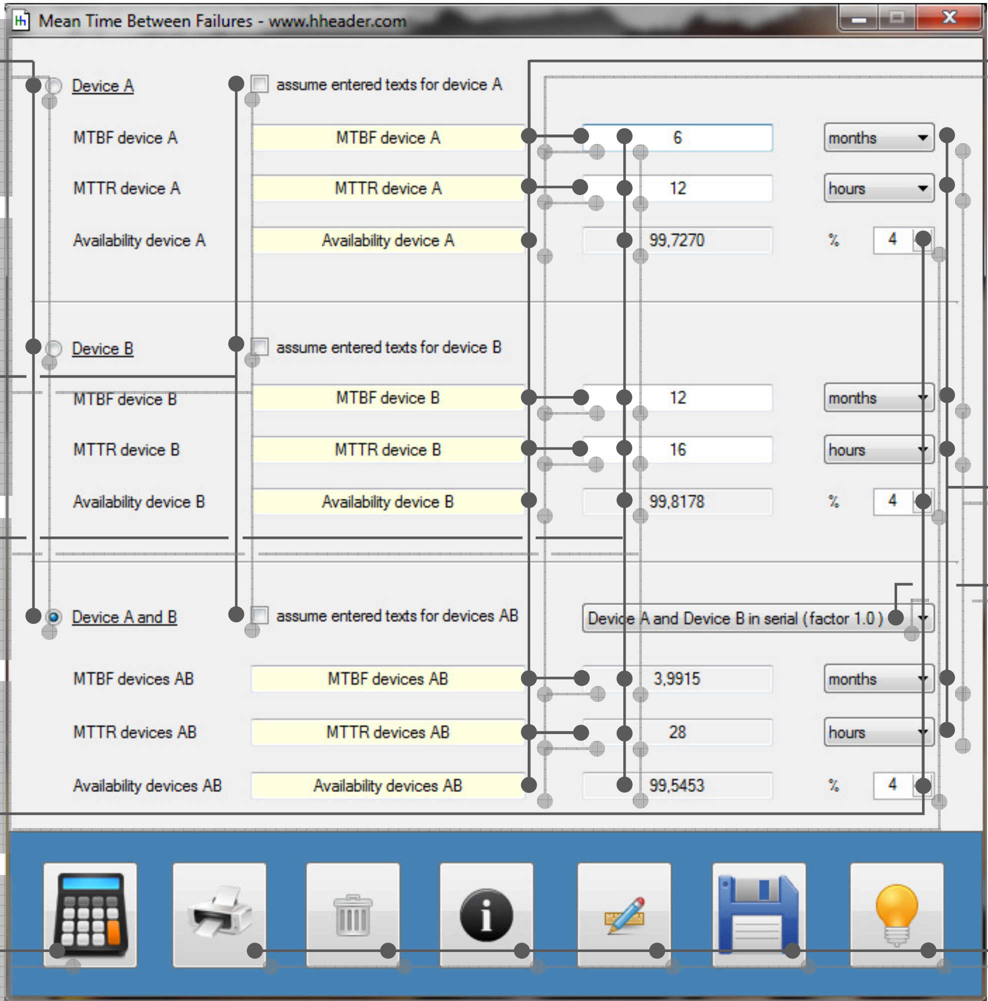


Figure 187: form MTBF – mean time between failures

Step 4:
Fill the Input-*TextBoxes*
I enter the values for the input variables. Regarding the values I should respect the variable limits and take care that the entered values are numeric. The designations are string variables. There are no checks for plausibility provided regarding the designations.

Step 3:
Select the time units
I can choose between different time units.

Step 5:
Select the connection case
I can choose if the devices A and B are connected in series or in parallel.

Step 9:
Further actions
After the calculation I can have the following options: Print Data, Erase Data, Program Information, Notes, Save or Restore Values. While printing a new calculation is executed automatically. Clicking the Erase-Button will empty all the *TextBoxes* at once.