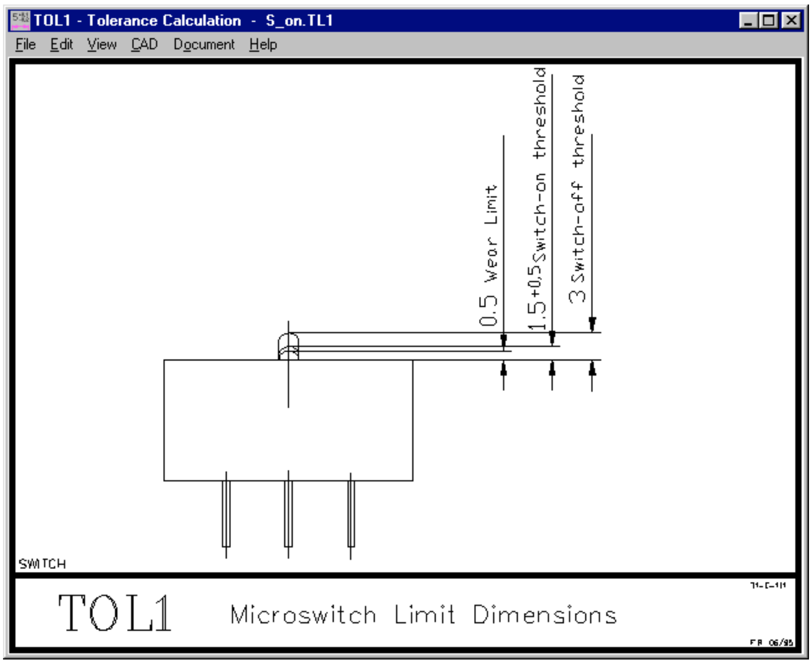
7. Application Example

An application example will show you how the tolerance calculation works. It is designed as a safety switch, used to turn off a machine. The design of the switching element is as follows:

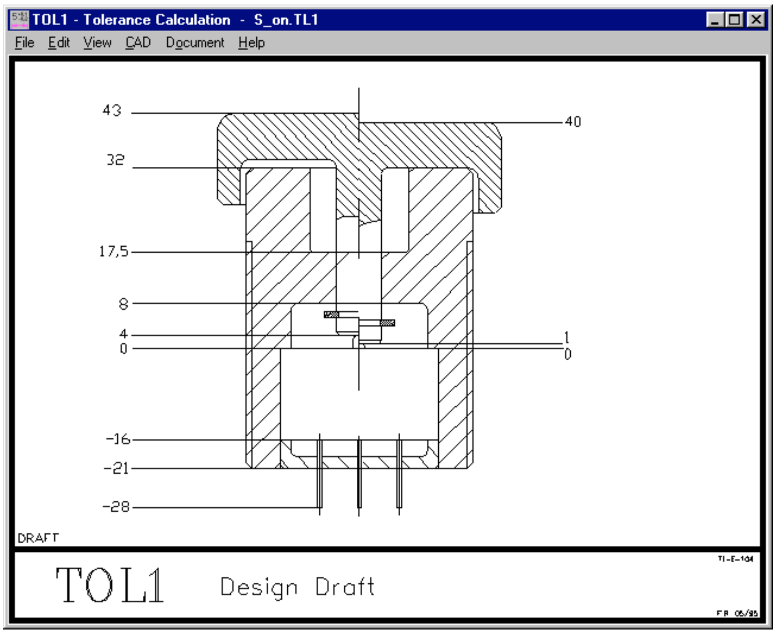


For safe use the switching zone for the actuator is as follows:
Position off: > 3.3 mm i.e. the switch must be completly relieved
Position on: > 1.5 mm: switch not yet guaranteed
< 0.5 mm: damage possible.

The tolerance calculation should show whether the switch points are adhered to. In addition the total length should be ascertained with tolerances.

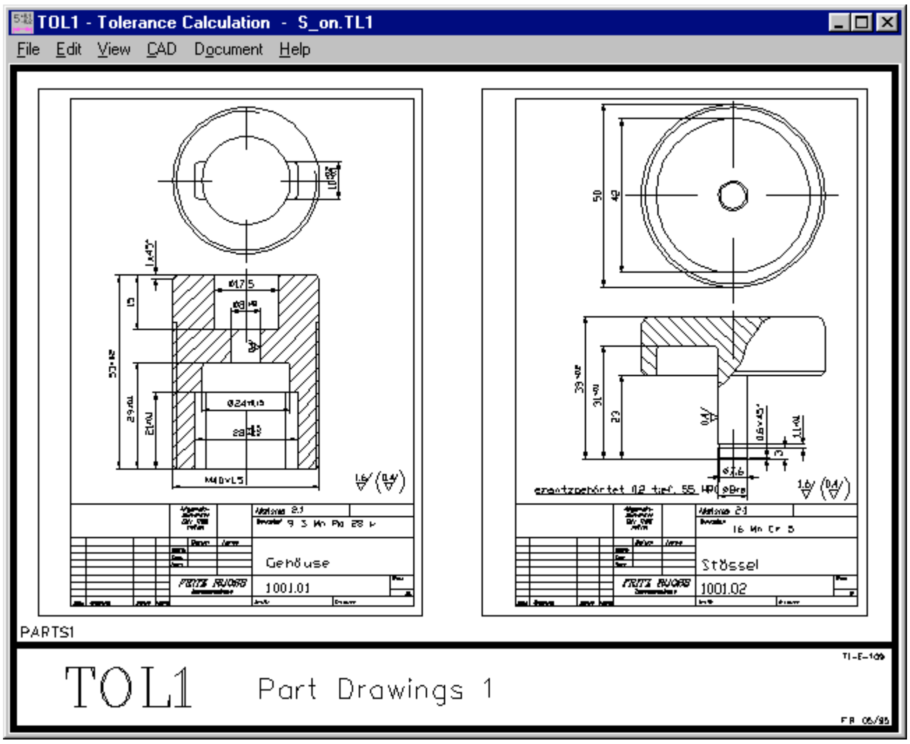
7.1. Design Draft

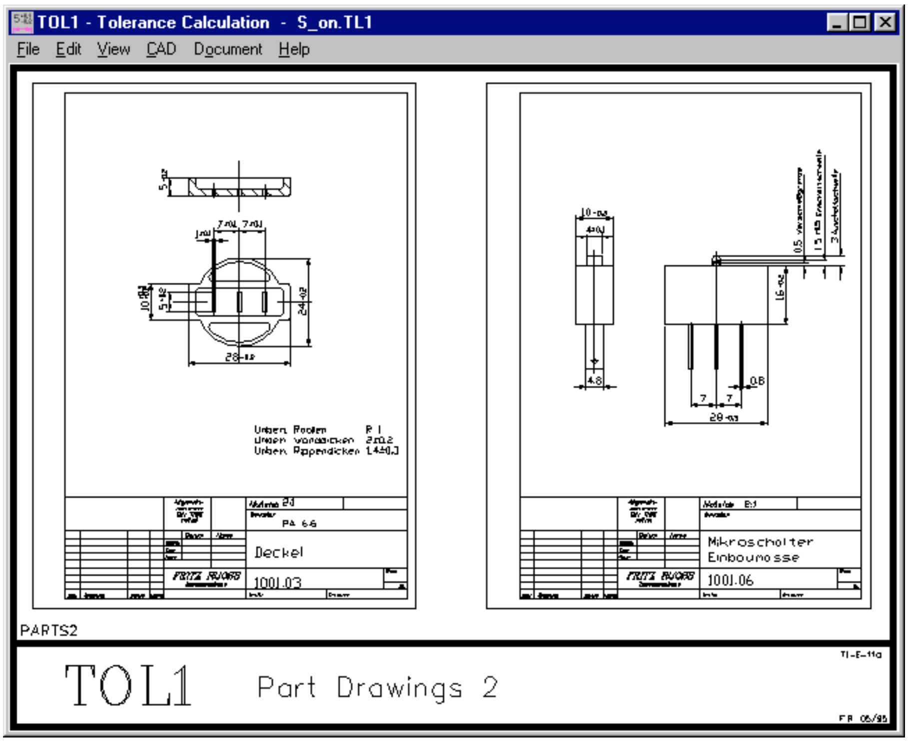
The micro switch is installed in a casing and covered with a lid. The micro switch is operated with a ram against the force of a compression spring.



7.2. Part Drawings

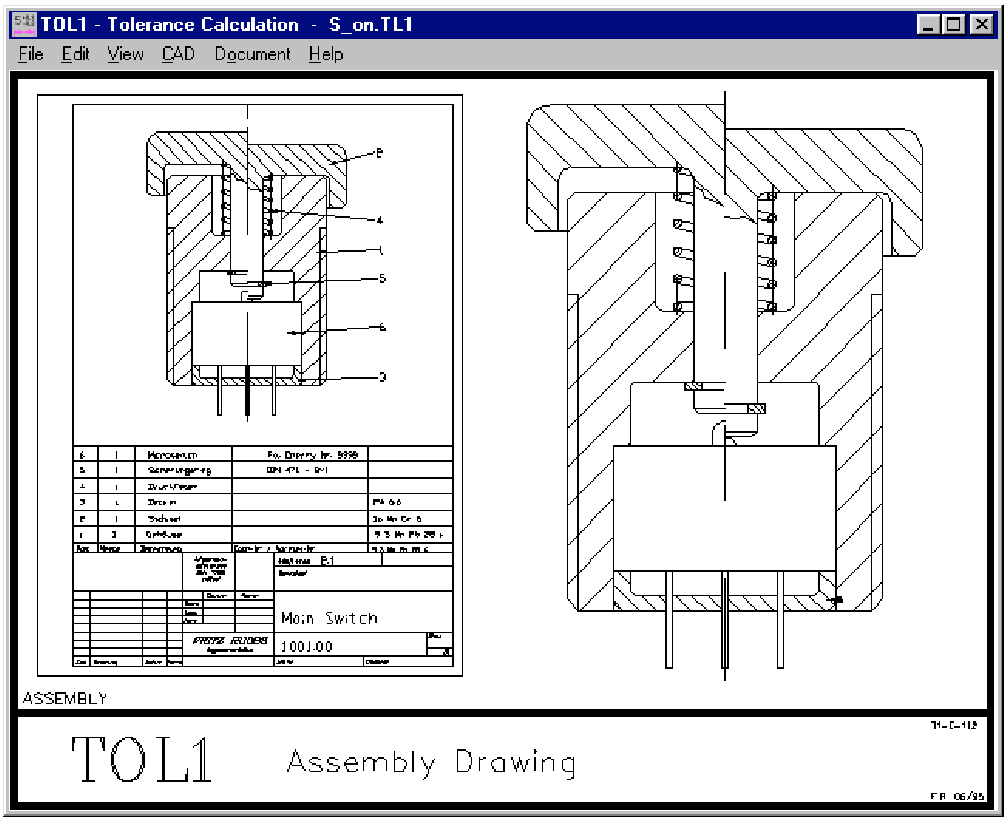
Drawings are created of case, ram, switch and cover.





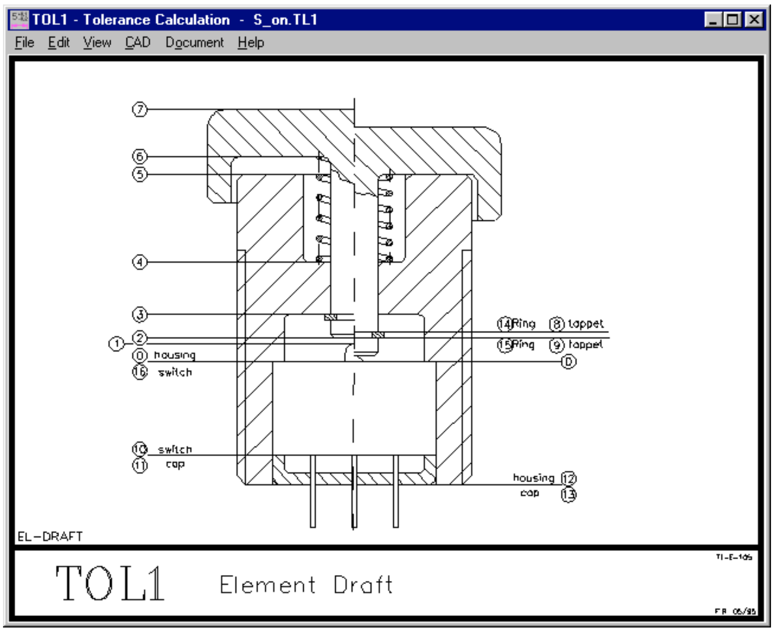
7.3. Assembly Drawing and Part List

The drawing contains case, ram and cover, the micro switch and also the standard parts: locking ring and compression spring.



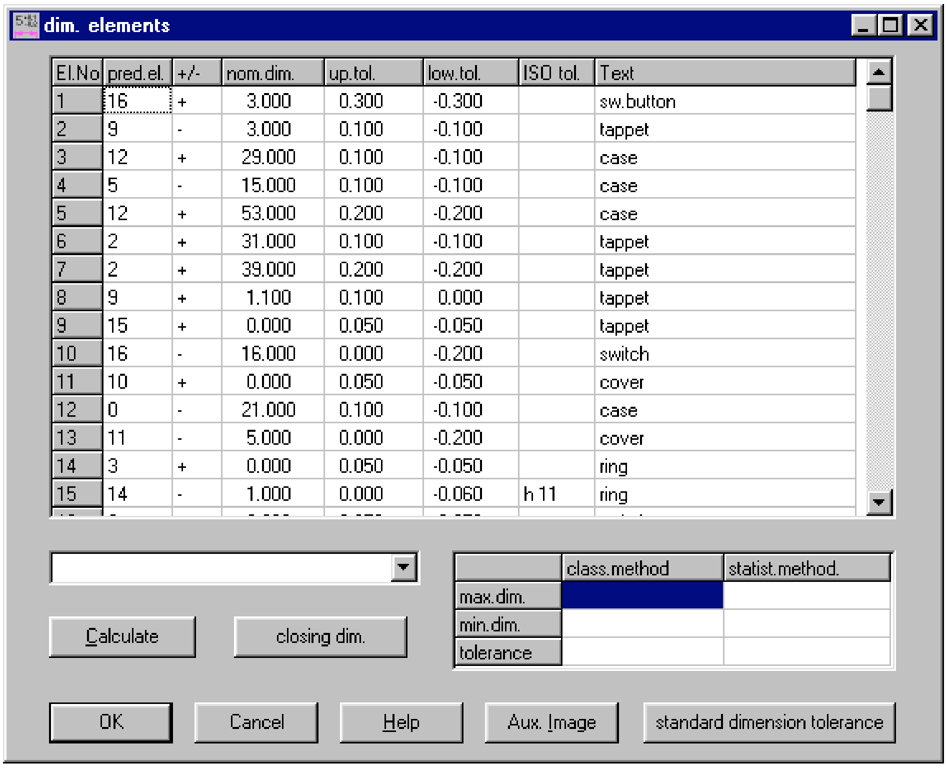
7.4. Element Draft

The preparation for the tolerance calculation begins with the element draft. The element 0 is the switch line chosen as root element. All further dimension elements are numbered. For calculation of the switching security it would suffice to list only the involved elements. However since one or other measurement is often required later such as total geometry, we calculate and list all important elements in the element draft and element table.



7.5. Element Table

For the tolerance calculation of the stop switch two different element tables must be prepared, one for the switch setting 'off' and one for 'on' (see example file S_ON and S_OFF).



El.No	pred.el.	+/-	nom.dim.	up.tol.	low.tol.	ISO tol.	Text
1	16	+	3.000	0.300	-0.300		sw.button
2	9	-	3.000	0.100	-0.100		tappet
3	12	+	29.000	0.100	-0.100		case
4	5	-	15.000	0.100	-0.100		case
5	12	+	53.000	0.200	-0.200		case
6	2	+	31.000	0.100	-0.100		tappet
7	2	+	39.000	0.200	-0.200		tappet
8	9	+	1.100	0.100	0.000		tappet
9	15	+	0.000	0.050	-0.050		tappet
10	16	-	16.000	0.000	-0.200		switch
11	10	+	0.000	0.050	-0.050		cover
12	0	-	21.000	0.100	-0.100		case
13	11	-	5.000	0.000	-0.200		cover
14	3	+	0.000	0.050	-0.050		ring
15	14	-	1.000	0.000	-0.060	h 11	ring

We begin with switch position 'off' and the casing as the root element 0 is here. First of all we input the elements which contain the root element 0 as predecessor (element 12). From element table or part drawings and element draft we get predecessor element, direction , nominal dimension as well as upper and lower deviation. The predecessor element of 12 is 0, the direction is -, the dimension is 21+/-0.1. The next input elements based on 12 follow, these are 3 and 5, and as last case element the no.4. Now we enter the micro switch elements, whose element 16 borders directly on element 0 of the casing. For surface roughness a tolerance can be entered of around ñ0.05. The elements 1 and 10 of the micro switch follow next. The cover element 11 is the same as element 10 of the switch. Since connection of the ram to the housing occurs via a safety ring, these elements, 14 and 15 have to be defined first. Finally the ram can be entered with its elements 2, 6, 7, 8 and 9.

Summing up a logically correct sequence of the elements in the element table:

12 - 3 - 5 - 4 - 16 - 1 - 10 - 11 - 13 - 14 - 15 - 9 - 8 - 2 - 6 - 7

There are two methods for creating the Element Table for the switch position "On":

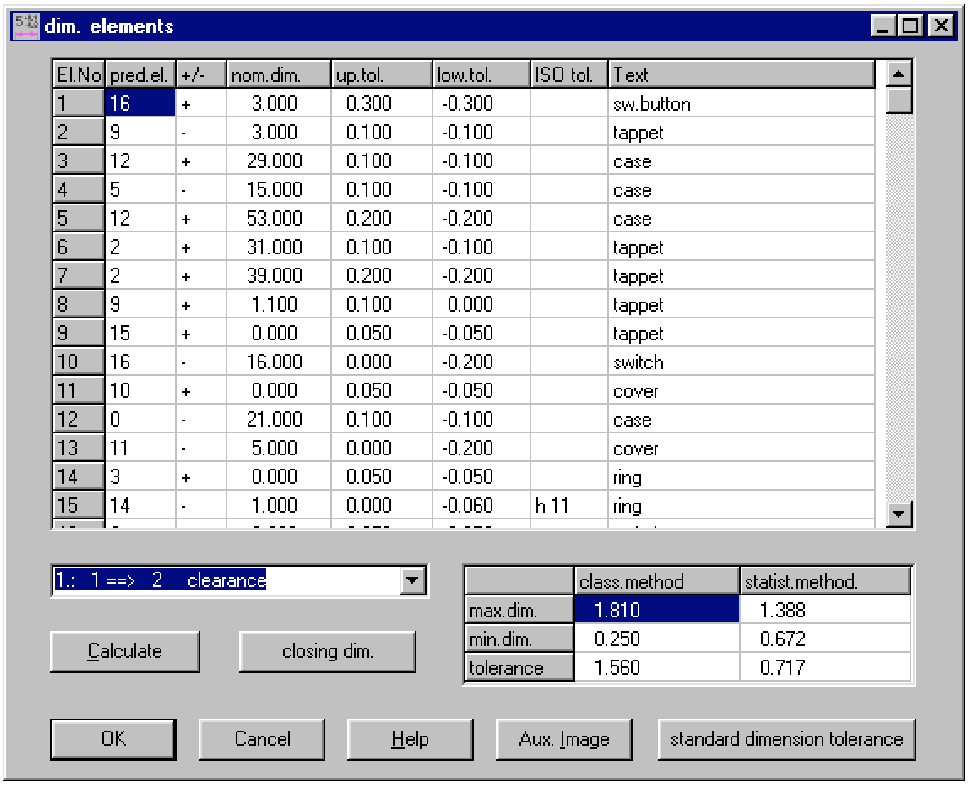
1. New input of all elements as described above
2. Modification of the differing data

Here the second method should be considered. Due to the different combinations between ram and case the predecessors of the involved elements change. The combination of elements for the position "OFF" connects the elements 3 - 14 - 15 - 9, whereas in the "ON" position the elements 5 - 6 are connect. The following changes result:

- * predecessor element 6 for input element 5
- * predecessor element 2 for input element 6
- * predecessor element 9 for input element 2
- * predecessor element 14 for input element 15
- * predecessor element 15 for input element 9

7.6. Tolerance Calculation with TOL1

If you have already created the element tables, TOL1 can be started. Enter the user password TRAIN. S_ON and S_OFF are the tolerance calculation files for switch position "ON" and "OFF", you can load them from the file menu, or you can enter the 16 elements under "Input Elements".



El.No	pred.el.	+/-	nom.dim.	up.tol.	low.tol.	ISO tol.	Text
1	16	+	3.000	0.300	-0.300		sw.button
2	9	-	3.000	0.100	-0.100		tappet
3	12	+	29.000	0.100	-0.100		case
4	5	-	15.000	0.100	-0.100		case
5	12	+	53.000	0.200	-0.200		case
6	2	+	31.000	0.100	-0.100		tappet
7	2	+	39.000	0.200	-0.200		tappet
8	9	+	1.100	0.100	0.000		tappet
9	15	+	0.000	0.050	-0.050		tappet
10	16	-	16.000	0.000	-0.200		switch
11	10	+	0.000	0.050	-0.050		cover
12	0	-	21.000	0.100	-0.100		case
13	11	-	5.000	0.000	-0.200		cover
14	3	+	0.000	0.050	-0.050		ring
15	14	-	1.000	0.000	-0.060	h 11	ring

	class.method	statist.method.
max.dim.	1.810	1.388
min.dim.	0.250	0.672
tolerance	1.560	0.717

Next the critical distances are entered. For switch position "OFF" this is 1 = > 2 and for position "ON" the distance 0 = > 2.

Under "View Crit.Dist." you can display or print out the results.

```
======================================================================
DIMENSIONAL STRUCTURE : 1 => 16 => 0 <= 12 <= 3 <= 14 <= 15 <= 9 <= 2
======================================================================
----------------------------------------------------------------------
1. Classic Method at constant distribution:

  1 ===>   2      Max.dim.    :    1.810                        0.810
                  Nom.dim.    :    1.000                1.000 --------
clearance         Min.dim.    :    0.250                       -0.750
----------------------------------------------------------------------

----------------------------------------------------------------------
2. Statistical method at Gaussian distribution

  1 ===>   2      Max.dim.    :    1.388                        0.358
                  Aver.dim.   :    1.030                1.030 --------
clearance         Min.dim.    :    0.672                       -0.358
----------------------------------------------------------------------
```

Off-Position (Excerpt)

```
----------------------------------------------------------------------
TOL1 - Tolerance Calculation      Version 9.1
License No. 0273  * * *  MOEN Incorporated  North Olmsted
H:\APPS\TP\TRAIN\S_off.TOL    date: 06/09/1999   time: 18:14
----------------------------------------------------------------------
Application Example
Stop switch in "OFF" position
Example from TOL1 Manual
======================================================================
El. Pred.   ±  Nom.dim.  Up.Dev. Low.Dev.    ISO    Text
======================================================================
  1    16   +     3.000    0.300   -0.300   .....   sw.button
  2     9   -     3.000    0.100   -0.100   .....   tappet
  3    12   +    29.000    0.100   -0.100   .....   case
  4     5   -    15.000    0.100   -0.100   .....   case
  5    12   +    53.000    0.200   -0.200   .....   case
  6     2   +    31.000    0.100   -0.100   .....   tappet
  7     2   +    39.000    0.200   -0.200   .....   tappet
  8     9   +     1.100    0.100    0.000   .....   tappet
  9    15   +     0.000    0.050   -0.050   .....   tappet
 10    16   -    16.000    0.000   -0.200   .....   switch
 11    10   +     0.000    0.050   -0.050   .....   cover
 12     0   -    21.000    0.100   -0.100   .....   case
 13    11   -     5.000    0.000   -0.200   .....   cover
 14     3   +     0.000    0.050   -0.050   .....   ring
 15    14   -     1.000    0.000   -0.060   h11     ring
 16     0   +     0.000    0.050   -0.050   .....   switch
999
----------------------------------------------------------------------


Closing dimensions for constant distribution
======================================================================
Distanc  Nom.dim.   Up.t.  L.tol.Max.clear.Min.clear. Comment
======================================================================
  1   2     1.000   0.810  -0.750     1.810     0.250 clearance
----------------------------------------------------------------------
 12  13     0.000   0.600  -0.200     0.600    -0.200 cover-case
----------------------------------------------------------------------
 12   7    64.000   0.560  -0.500    64.560    63.500 total length
----------------------------------------------------------------------
  5   6     3.000   0.660  -0.600     3.660     2.400 stroke
----------------------------------------------------------------------

Closing dimensions for Gaussian distribution
======================================================================
Distanc  Mid.dim.   Up.t.  L.tol.Max.clear.Min.clear. Comment
======================================================================
  1   2     1.030   0.358  -0.358     1.388     0.672 clearance
----------------------------------------------------------------------
 12  13     0.200   0.187  -0.187     0.387     0.013 cover-case
----------------------------------------------------------------------
 12   7    64.030   0.257  -0.257    64.287    63.773 total length
----------------------------------------------------------------------
  5   6     3.030   0.275  -0.275     3.305     2.755 stroke
----------------------------------------------------------------------
```

```
======================================================================
closing dim.
======================================================================
clearance
cover-case
total length
stroke
----------------------------------------------------------------------
```

The smallest distance between switch button and ram (1 = > 2) is 0.25 mm, which remains as a safety.

You can see from the calculation 12 = > 13 results, that the cover line differs from -0.2 to +0.6mm.

Distance 7= > 12 is the total length of the stop switch.

Distance 5= > 6 is the switch stroke, which can fluctuate between 2.4 mm and 3.66 mm. You will get the same result if you calculate the distance 3= > 14 in the ON position.

Output S_ON (stop switch at ON-position)

```
----------------------------------------------------------------------
       TOL1 - Tolerance Calculation      Version 9.1
       License No. 0273  * * *  MOEN Incorporated  North Olmsted
       H:\APPS\TP\TRAIN\S_on.TOL    date: 06/09/1999   time: 18:19
       ----------------------------------------------------------------------
       Application Example
       Stop switch in "ON" position
       Example for TOL1 Manual
       ======================================================================
       El. Pred.   ±  Nom.dim.  Up.Dev. Low.Dev.    ISO    Text
       ======================================================================
         1    16   +     3.000    0.300   -0.300   .....   sw.button
         2     6   -    31.000    0.100   -0.100   .....   tappet
         3    12   +    29.000    0.100   -0.100   .....   case
         4     5   -    15.000    0.100   -0.100   .....   case
         5    12   +    53.000    0.200   -0.200   .....   case
         6     5   +     0.000    0.050   -0.050   .....   tappet
         7     2   +    39.000    0.200   -0.200   .....   tappet
         8     9   +     1.100    0.100    0.000   .....   tappet
         9     2   +     3.000    0.100   -0.100   .....   tappet
        10    16   -    16.000    0.100   -0.100   .....   switch
        11    10   +     0.000    0.050   -0.050   .....   cover
        12     0   -    21.000    0.100   -0.100   .....   case
        13    11   -     5.000    0.000   -0.200   .....   cover
        14    15   +     1.000    0.000   -0.060   h11     ring
        15     9   +     0.000    0.050   -0.050   .....   ring
        16     0   +     0.000    0.050   -0.050   .....   switch
       999
       ----------------------------------------------------------------------

       Closing dimensions for constant distribution
       ======================================================================
       Distanc  Nom.dim.   Up.t.  L.tol.Max.clear.Min.clear. Comment
       ======================================================================
         0   2     1.000   0.450  -0.450     1.450     0.550 switch-tappet
       ----------------------------------------------------------------------
        14   3     3.000   0.660  -0.600     3.660     2.400 stroke
       ----------------------------------------------------------------------
        13  12     0.000   0.300  -0.500     0.300    -0.500 cover
       ----------------------------------------------------------------------
        12   7    61.000   0.550  -0.550    61.550    60.450 total length
       ----------------------------------------------------------------------
         5   0   -32.000   0.300  -0.300   -31.700   -32.300 ...............
       ----------------------------------------------------------------------

       Closing dimensions for Gaussian distribution
```

Distanc		Mid.dim.	Up.t.	L.tol.	Max.clear.	Min.clear.	Comment
0	2	1.000	0.250	-0.250	1.250	0.750	switch-tappet
14	3	3.030	0.275	-0.275	3.305	2.755	stroke
13	12	-0.100	0.187	-0.187	0.087	-0.287	cover
12	7	61.000	0.304	-0.304	61.304	60.696	total length
5	0	-32.000	0.224	-0.224	-31.776	-32.224	....

closing dim.
switch-tappet
stroke
cover
total length

The smallest distance between switch line and ram is 0.55 mm, a safety margin of 0.05 mm remains up to the wear limit of 0.5 mm. For the largest distance of 1.45 mm a safety margin of 0.05 mm remains up to the switching point of 1.5mm.

7.7. Optimization

The results are very good, however, in order to obtain an additional safety margin, you can reduce the difference between maximum and minimum dimension to the distance 0 = > 2, in order to have an even larger reserve than 0.05 mm. There are two methods to accomplish this:

1. Shortening the dimension chain
2. Reduction of the tolerances

Both methods will now be demonstrated:

Optimization by shortening the dimension chain

Using the element draft all elements within a group are summed up. If the component chain is more than two elements long you can try to reduce the chain by altering the dimension structure.

```
======================================================================
DIMENSIONAL STRUCTURE : 0 <= 12 <= 5 <= 6 <= 2
======================================================================
----------------------------------------------------------------------
1. Classic Method at constant distribution:

  0 ===>   2      Max.dim.    :    1.450                       0.450
                  Nom.dim.    :    1.000             1.000 --------
switch-tappet     Min.dim.    :    0.550                      -0.450
----------------------------------------------------------------------
```

In our example following change emerges:

Predecessor of element 5 is 0, dimension is 32 +/- 0.15

Result after re-calculation:

```
======================================================================
DIMENSIONAL STRUCTURE : 0 <= 5 <= 6 <= 2
======================================================================
----------------------------------------------------------------------
1. Classic Method at constant distribution:

  0 ===>   2      Max.dim.    :    1.300                       0.300
                  Nom.dim.    :    1.000             1.000 --------
switch-pestle     Min.dim.    :    0.700                      -0.300
----------------------------------------------------------------------
```

```
---------------------------------------------------------------------
 TOL1 - Tolerance Calculation      Version 9.1
 License No. 0274  * * *  Valeo Electronique  Creteil
 H:\APPS\TP\TRAIN\S_on_opt.TOL    date: 06/09/1999   time: 18:51
 ----------------------------------------------------------------------
 Application Example
 Stop switch in "ON" position
 Example for TOL1 Manual
 ======================================================================
 El. Pred.   ±  Nom.dim.  Up.Dev. Low.Dev.    ISO    Text
 ======================================================================
   1    16   +     3.000    0.300   -0.300   .....   sw.button
   2     6   -    31.000    0.100   -0.100   .....   pestle
   3    12   +    29.000    0.100   -0.100   .....   case
   4     5   -    15.000    0.100   -0.100   .....   case
   5     0   +    32.000    0.150   -0.150   .....   case
   6     5   +     0.000    0.050   -0.050   .....   pestle
   7     2   +    39.000    0.200   -0.200   .....   pestle
   8     9   +     1.100    0.100    0.000   .....   pestle
   9     2   +     3.000    0.100   -0.100   .....   pestle
  10    16   -    16.000    0.100   -0.100   .....   switch
  11    10   +     0.000    0.050   -0.050   .....   cover
  12     0   -    21.000    0.100   -0.100   .....   case
  13    11   -     5.000    0.000   -0.200   .....   cover
  14    15   +     1.000    0.000   -0.060   h11     ring
  15     9   +     0.000    0.050   -0.050   .....   ring
  16     0   +     0.000    0.050   -0.050   .....   switch
 999
 ----------------------------------------------------------------------


 Closing dimensions for constant distribution
 ======================================================================
 Distanc  Nom.dim.   Up.t.  L.tol.Max.clear.Min.clear. Comment
 ======================================================================
   0   2     1.000   0.300  -0.300     1.300     0.700 switch-pestle
 ----------------------------------------------------------------------
  14   3     3.000   0.710  -0.650     3.710     2.350 stroke
 ----------------------------------------------------------------------
  13  12     0.000   0.300  -0.500     0.300    -0.500 cover
 ----------------------------------------------------------------------
  12   7    61.000   0.600  -0.600    61.600    60.400 total length
 ----------------------------------------------------------------------

 Closing dimensions for Gaussian distribution
 ======================================================================
 Distanc  Mid.dim.   Up.t.  L.tol.Max.clear.Min.clear. Comment
 ======================================================================
   0   2     1.000   0.187  -0.187     1.187     0.813 switch-pestle
 ----------------------------------------------------------------------
  14   3     3.030   0.262  -0.262     3.292     2.768 stroke
 ----------------------------------------------------------------------
  13  12    -0.100   0.187  -0.187     0.087    -0.287 cover
 ----------------------------------------------------------------------
  12   7    61.000   0.292  -0.292    61.292    60.708 total length
 ----------------------------------------------------------------------
```

Optimization by Reduction of Tolerances

First we will review again on screen the ouput of the critical distances.

```
=======================================================================
DIMENSIONAL STRUCTURE : 0 <= 12 <= 5 <= 6 <= 2
=======================================================================
-----------------------------------------------------------------------
1. Classic Method at constant distribution:

  0 ===>   2      Max.dim.    :    1.450                         0.450
                  Nom.dim.    :    1.000                1.000 --------
switch-tappet     Min.dim.    :    0.550                        -0.450
-----------------------------------------------------------------------
```

You can see that the distance from 0 to 2 is a chain of 4 dimensions. You can reduce the tolerance of one or all of the four dimensions now.

In the example the following were changed:

5 = > 12 from 53 +/- 0.2 to 53 +/- 0.1
12 = > 0 from 21 +/- 0.1 to 21 +/- 0.05

Output after re-calculation:

```
=======================================================================
DIMENSIONAL STRUCTURE : 0 <= 12 <= 5 <= 6 <= 2
=======================================================================
-----------------------------------------------------------------------
1. Classic Method at constant distribution:

  0 ===>   2      Max.dim.    :    1.300                         0.300
                  Nom.dim.    :    1.000                1.000 --------
switch-pestle     Min.dim.    :    0.700                        -0.300
-----------------------------------------------------------------------
```

Printout:

```
----------------------------------------------------------------------------
       TOL1 - Tolerance Calculation      Version 9.1
       License No. 0274  * * *  Valeo Electronique  Creteil
       H:\APPS\TP\TRAIN\S_on_op2.TOL    date: 06/09/1999   time: 19:01
       -----------------------------------------------------------------------
       Application Example
       Stop switch in "ON" position
       Example for TOL1 Manual
       =======================================================================
       El. Pred.   ±  Nom.dim.  Up.Dev. Low.Dev.    ISO    Text
       =======================================================================
         1    16   +     3.000    0.300   -0.300   .....   sw.button
         2     6   -    31.000    0.100   -0.100   .....   pestle
         3    12   +    29.000    0.100   -0.100   .....   case
         4     5   -    15.000    0.100   -0.100   .....   case
         5    12   +    53.000    0.100   -0.100   .....   case
         6     5   +     0.000    0.050   -0.050   .....   pestle
         7     2   +    39.000    0.200   -0.200   .....   pestle
         8     9   +     1.100    0.100    0.000   .....   pestle
         9     2   +     3.000    0.100   -0.100   .....   pestle
        10    16   -    16.000    0.100   -0.100   .....   switch
        11    10   +     0.000    0.050   -0.050   .....   cover
        12     0   -    21.000    0.050   -0.050   .....   case
        13    11   -     5.000    0.000   -0.200   .....   cover
        14    15   +     1.000    0.000   -0.060   h11     ring
        15     9   +     0.000    0.050   -0.050   .....   ring
        16     0   +     0.000    0.050   -0.050   .....   switch
       999
```

Closing dimensions for constant distribution

Distanc		Nom.dim.	Up.t.	L.tol.	Max.clear.	Min.clear.	Comment
0	2	1.000	0.300	-0.300	1.300	0.700	switch-pestle
14	3	3.000	0.560	-0.500	3.560	2.500	stroke
13	12	0.000	0.250	-0.450	0.250	-0.450	cover
12	7	61.000	0.450	-0.450	61.450	60.550	total length
5	0	-32.000	0.150	-0.150	-31.850	-32.150	....

Closing dimensions for Gaussian distribution

Distanc		Mid.dim.	Up.t.	L.tol.	Max.clear.	Min.clear.	Comment
0	2	1.000	0.158	-0.158	1.158	0.842	switch-pestle
14	3	3.030	0.214	-0.214	3.244	2.816	stroke
13	12	-0.100	0.166	-0.166	0.066	-0.266	cover
12	7	61.000	0.250	-0.250	61.250	60.750	total length
5	0	-32.000	0.112	-0.112	-31.888	-32.112	....

You can see here that the same result of 1+/-0.3 been achieved with a different method. Even better results can achieved when considering the values of the Gaussian distribution, which is described in the next chapter.