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KISSsoft Instruction 063

Wear

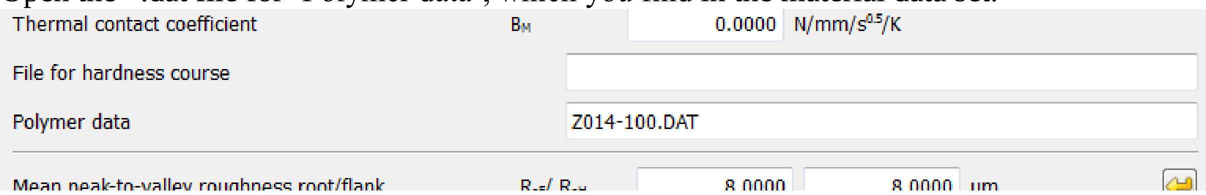
Plastic Gears: Wear is the main limiting factor for dry running plastic gears. For lubricated plastic gears this is not the case; tooth breakage or deformation by too high temperature are the usual failure modes.

Steel Gears: KISSsoft is planning for Release 2011 an option for calculation of wear on low speed gears (so called cold scoring).

Wear on Plastic Gears

1. Input of Wear Coefficient

Open the *.dat file for 'Polymer data', which you find in the material data set.



Wear coefficients are different for dry-running, grease lubrication or oil lubrication.

Z2014-100.DAT - Editor

Datei Bearbeiten Format Ansicht ?

```
-- Data for Temperature Range of WEAR Data (0: No Data)
-- SchmierTyp 0:Oil 1:Grease 2:Dry-Running
:TABLE FUNCTION MinTempWear
      INPUT X SchmierTyp TREAT LINEAR
DATA
      0      1      2
      0      0   15.0
END

-- Data for Temperature Range of WEAR Data (0: No Data)
-- SchmierTyp 0:Oil 1:Grease 2:Dry-Running
:TABLE FUNCTION MaxTempWear
      INPUT X SchmierTyp TREAT LINEAR
DATA
      0      1      2
      0      0   70.0
END

-- Data for wear (PROVISORY! From Dissertation R.Feulner, 2008) Dependency from Temperature unkno
-- in 10^-6 mm3/Nm
:TABLE FUNCTION KwearDry
      INPUT X ZahnTempFlanke TREAT LINEAR
DATA
    -20     23     40     90    120
   1.03   1.03   1.03   1.03   1.03
END
```

Here an example for Wear Coefficient (for POM) for dry running, data can be used between 15°C and 70°C.
(Temperature input MUST be in °C)

2. Materials with Wear Coefficients available in KISSsoft

In the material designation you find between [..] the information about available data.

Gear 2 — POM, Thermoplastic (POM, PPA, etc.), untreated [SBFWd]

Lubrication

PA 12, Thermoplastic PA, untreated, [BF]
PA 66, Thermoplastic PA, untreated, [BF]
POM, Thermoplastic (POM, PPA, etc.), untreated, [SBFWd]
Hostaform C9021, Thermoplastic (POM, PPA, etc.), untreated, [BF]
Pressholz, Molded laminated wood, untreated, [BF]
PBT, Thermoplastic (POM, PPA, etc.), untreated, [F] Data from book Ehrenstein
PEEK, Thermoplastic (POM, PPA, etc.), untreated, [SBFo] Data from VICTREX, based on Test results
LUBRICOMP UCL-4036A HS/UCL36AS, Thermoplastic (POM, PPA, etc.), fiber reinforced, [SWd] PPA, Carbon Fibre, PTFE, by SABIC Innovative Plastic

Syntax is explained in the Help:

It takes a great amount of time and effort to determine all the data for calculating the strength of plastics. For this reason, you can also enter plastics with a limited amount of data in the database.

For this reason, a comment can be added for strength data for all plastics which state which data is present and therefore which type of calculations can be performed.

The entry has this format:

[SBFoFgFdWoWgWd]

Abbreviations:

S data for the static root strength calculation is present
B Wöhler lines for calculating the root endurance limit (VDI) are present
F Wöhler lines for all lubrication types for flank endurance calculation (VDI) are present
Fo Wöhler lines for oil lubrication for flank endurance calculation (VDI) are present
Fg Wöhler lines for the grease lubrication for flank endurance calculation (VDI) are present
Fd Wöhler lines for the dry-run for the flank endurance calculation (VDI) are present
Fgd means: Wöhler lines for grease and dry-runs for the flank are present, etc.
W Wear coefficients for all lubrication types are present for wear calculation
Wo Wear coefficients for oil lubrication are present for wear calculation
Wg Wear coefficients for grease lubrication are present for wear calculation
Wd Wear coefficients for dry runs are present for wear calculation

3. How to get Wear Coefficient data

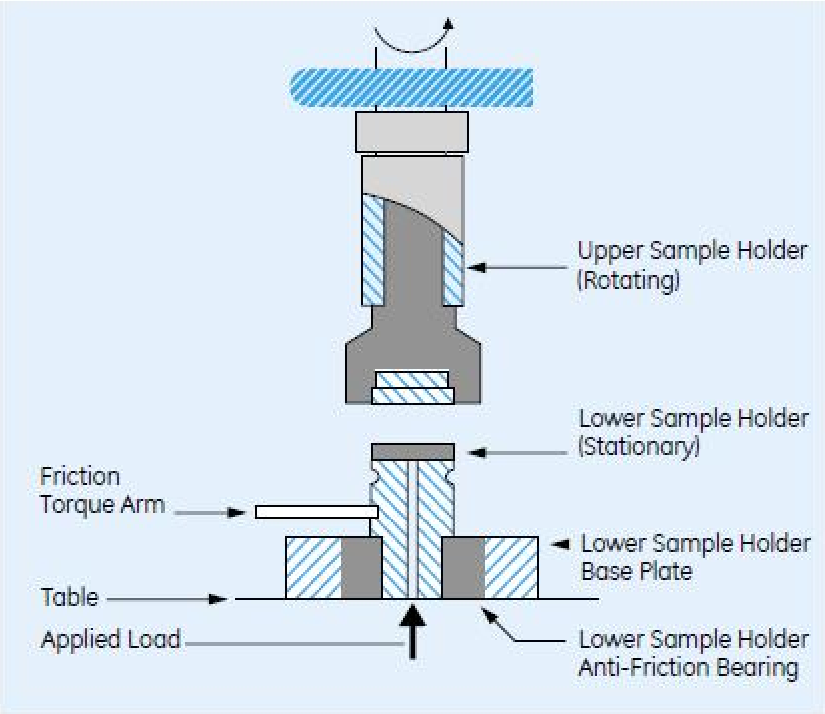
The information here presented is based on data documented by LUBRICOMP (by SABIC Innovative Plastic).

In the LUBRICOMP catalog you find a wear coefficient, called KLNP.

Example:
Lubricomp AL-4030: KLNP = 101*10^-10 (in5 min) / (ft lb hr)

KLNP was measured with thrust washer test apparatus.

Figure 6
Thrust Washer Test Appartus



KLNP in the formula for wear
Original formula (in LNP Doc, page 3) is:

$W_{(in3)} = K_{LNP\,(in5*min/ft/lb/hr)} * P_{(lbs/in2)} * V_{(ft/min)} * T_{(hr)}$

As the test is performed on the Thrust Washer Apparatus, the wear is basically loss of thickness of the plastic washer.
$K_{LNP\,(in5*min/ft/lb/hr)}$ as documented in table 1 (K_{LNP} Moving) is calculated directly using W=Material loss (in3), P = Pressure used in the test (lb/in2), V = Velocity used in the test (ft/min) and T = Hours the test was running (hr).

We can get (important for gears) **the wear depth δ_w** from this test by:

$W_{(in3)} = \delta_{w(in)} * A_{(in3)}$

A : Washer surface = 0.348 in2

So for one-dimensional wear:

$\delta_{w(in)} = W_{(in3)} / A_{(in2)} = K_{LNP\ (in5*min/ft/lb/hr)} / 0.342_{(in2)} * P_{(lbs/in2)} * V_{(ft/min)} * T_{(hr)}$

we use $K_{LNP\delta}$:

$K_{LNP\delta\ (in3*min/ft/lb/hr)} = K_{LNP}/0.342$

$K_{LNP\delta}$ is given in (in^3 min) / (ft lb hr), we prefer the factor in mm, sec, N

Conversion:
1 hr = 3600 sec
so $K_{LNP\delta}$ / (3600) is in (in3 min) / (ft lb sec)

1 ft/min = 5.08 mm/sec
so $K_{LNP\delta}$ / (3600*5.08) is in (in3 sec) / (mm lb sec)

1 lb/in2 = 0.00689 N/mm2
so $K_{LNP\delta}$ / (3600*5.08*0.00689) is in (in mm2 sec) / (mm N sec)

1 in = 25.4 mm
so $K_{LNP\delta}$ * 25.4/ (3600*5.08*0.00689) is in (mm mm2 sec) / (mm N sec)

- ➔ $K_{LNP\delta}$ * 0.2015 is in (mm2 / N); we define this value as $K_{LNP\delta metric}$
- ➔ $K_{LNP\delta metric} = K_{LNP\delta} * 0.2015$

If we use the values K_{LNP} from table 1 ($K_{LNP\delta\ (in3*min/ft/lb/hr)} = K_{LNP}/0.342$):

- ➔ $K_{LNP\delta metric} = K_{LNP} * 0.5892$ (mm2 / N)

After literature research [1], we found that generally not mm2/N/10^10 is used, but mm3/Nm/10^6, therefore we join this method:

- ➔ $K_{LNP\delta}$ (mm3/Nm/10^6) = 0.1 * $K_{LNP\delta metric}$ (mm2/N/10^10) = K_{LNP} * 0.05892

Example:
Lubricomp AL-4030: $K_{LNP\delta metric}$ = 101 * 0.5892 *10^-10 = 59.5*10^-10 mm2/N
Lubricomp AL-4030: $K_{LNP\delta}$ = 101 * 0.05892 *10^-6 = 5.95*10^-6 mm3/Nm

- ➔ In KISSsoft we define the Wear Coefficient as 10^-6 mm3/Nm!

4. Mathematical definition of wear on tooth flank

Using K_{LNP} for gears

We would like to get the wear on a point of the flank in mm (wear depth).
Wear formula:

$\delta_{w\ (mm)} = K_{LNP\delta metric\ (mm2/N)} * P_{(N/mm2)} * V_{(mm/s)} * T_{(s)}$

$\delta_{w\ (mm)} = 0.001 * K_{LNP\delta\ (mm3/Nm)} * P_{(N/mm2)} * V_{(mm/s)} * T_{(s)}$

Applying to gears, given data (in the point of contact):

F (N) Load

b (mm)	Face width
v_{p1}, v_{p2} (mm/s)	Velocity tangential to the flank of gear1, gear2
$v_{p1,2}*\Delta t$ (mm)	Moving distance of a point on the flank (Gear1, 2)
v_g (mm/s) = $v_{p1} - v_{p2}$	Sliding velocity
Δt (s)	Time

Applying to gears, wear calculation:

$v_g*\Delta t$ (mm)	Sliding distance
$A = b*(v_{pi}*\Delta t)$	Surface
$P = F / b/(v_{pi}*\Delta t)$	Pressure
δ_w (mm)	Wear depth (mm)

$\delta_{w\_i} = 1000*K_{LNP\delta\_i} * F / b / (v_{pi}*\Delta t)* v_g*\Delta t;$ $i = 1,2$

Formula for Wear depth on gears:

$\delta_{w\_i} = 0.001*K_{LNP\delta\_i} * F * v_g / b / v_{p\_i};$ $i = 1,2$

Or, using the specific sliding $\zeta = v_g/v_{p\_i}$:

$\delta_{w\_i} = 0.001*K_{LNP\delta\_i} * F * \zeta_{\_i} / b;$ $i = 1,2$

Wear after n cycles:

$\delta_{w\_i} = n * 0.001*K_{factor\delta\_i} * F / b * \zeta_{\_i};$ $i = 1,2$

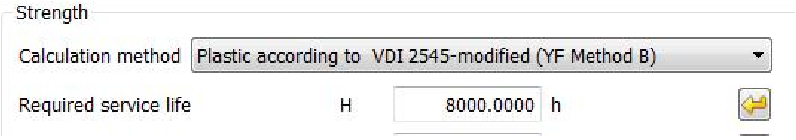
This is exactly the same formula as in the Dissertation of R. Feulner [1] (equation 6.1).

Examples for $K_{factor\delta\_i}$ (from [1]):
- for POM meshing with steel, 23°C, $K_{factor\delta}$ = 1.03 * 10^-6 mm3/Nm
- for PBT meshing with steel, 23°C, $K_{factor\delta}$ = 3.69 * 10^-6 mm3/Nm

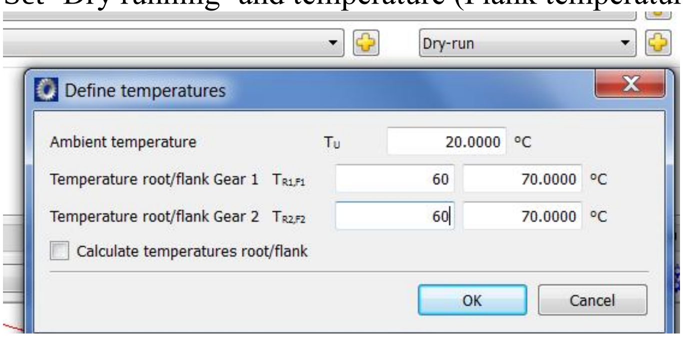
[1]: R.Feulner, Verschleiss trocken laufender Kunststoffgetriebe, Lehrstuhl Kunststofftechnik, Erlangen, 2008.

5. Wear calculation with KISSsoft

Set required Life time accordingly (wear is proportional to service life):



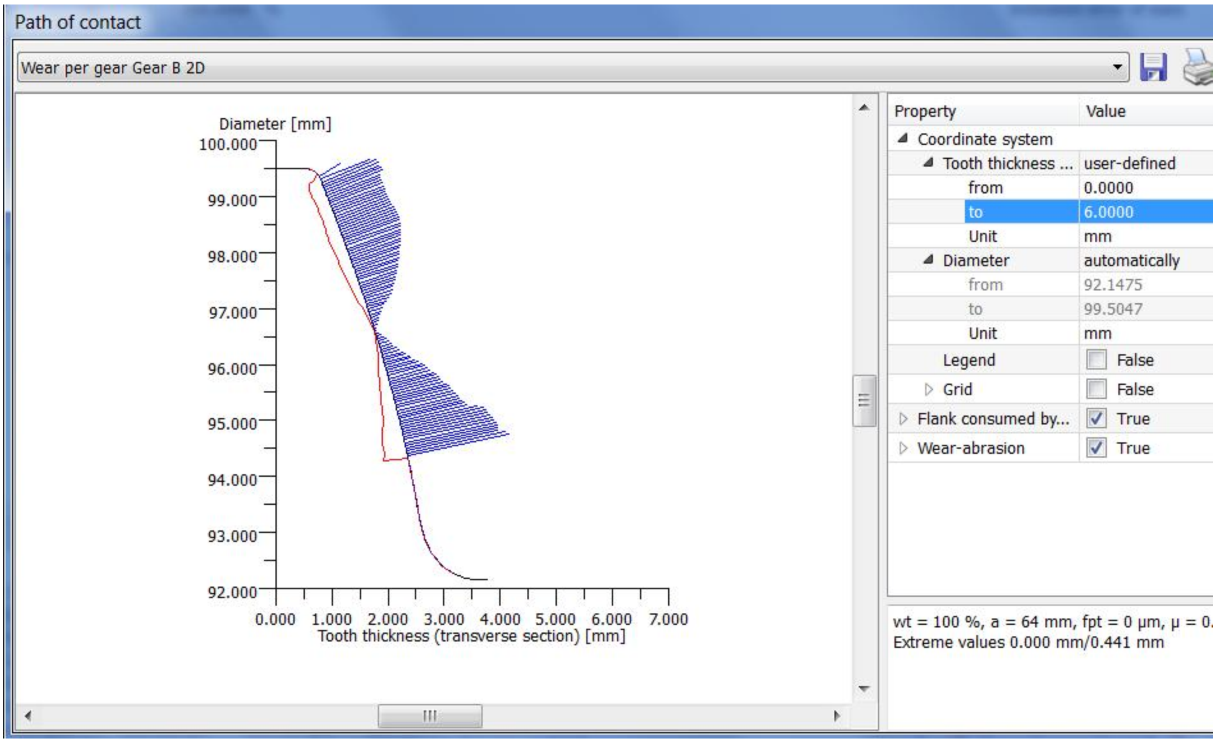
Set 'Dry running' and temperature (Flank temperature for wear coef.)



Wear calculation result in the report (without accurate calculation of tooth contact – path of contact):

```
4a. WEAR

Line load at reference diameter (N/mm)    [w]                           7.13
Loss factor                               [HV]                          0.178
Wear factor (mm^3/Nm/10^6)                [Jw]                                      1.03
Normal tooth thickness in pitch circle (mm)
                                          [sn]                                      1.97
Maximum permissible wear (%)              [Wlimit]                                 20.00
Boundary value for flank-removal (mm)     [delWlimn]                                0.39
Wear removal (mm)                         [delWn(VDI2736)]                          0.231
Safety against wear                       [SW]                                      1.70

Calculation of local wear with speeds and load distribution according to method A
Calculation was not carried out. (Required is the use of the calculation method for path of
contact under load.)

Important notice:
 The wear factors Jw are normally determined for plastic-steel combination.
 If other materials are combined, a considerable difference can occur.
 The calculation should give indications about possible service life,
but values are not yet enough tested in praxis..
```

For accurate results, use calculation of tooth contact – path of contact!

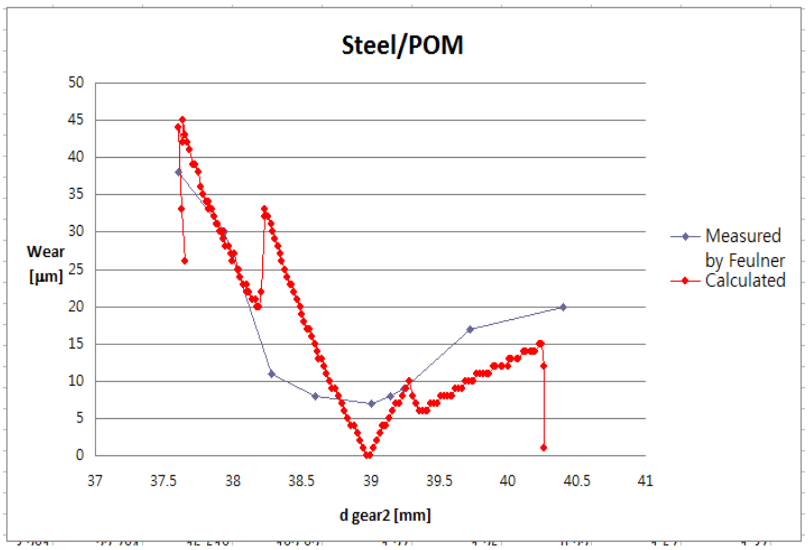


Red line: Worn flank in real dimensions
Note: Wear is calculated in one step from ideal flank to used flank after 8000 h, intermediate steps are not considered, explication see below.

Wear calculation result in the report (with accurate calculation of tooth contact – path of contact):

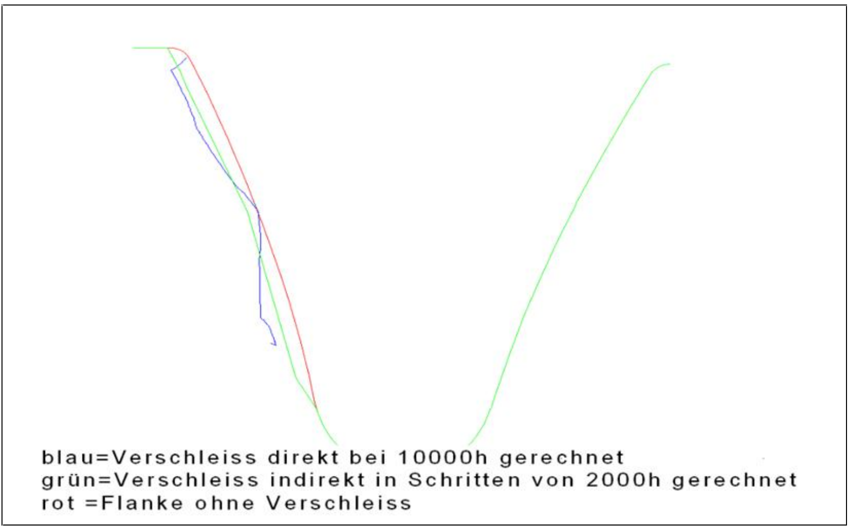
```
4a. WEAR

Line load at reference diameter (N/mm)    [w]                           7.13
Loss factor                               [HV]                          0.178
Wear factor (mm^3/Nm/10^6)                [Jw]                                    1.03
Normal tooth thickness in pitch circle (mm)
                                          [sn]                                    1.97
Maximum permissible wear (%)              [Wlimit]                               20.00
Boundary value for flank-removal (mm)     [delWlimn]                              0.39
Wear removal (mm)                         [delWn(VDI2736)]                        0.231
Safety against wear                       [SW]                                    1.70

Calculation of local wear with speeds and load distribution according to method A
Medium wear removal (mm)                  [delWn]              0.000              0.210
Safety against wear                       [SW]                                    1.87
```

6. Comparing calculation with measurements



Comparing KISSsoft calculation with measurement by [1].
Medium wear layer: Measured 16.4 µ; Calculated 17.8 µ

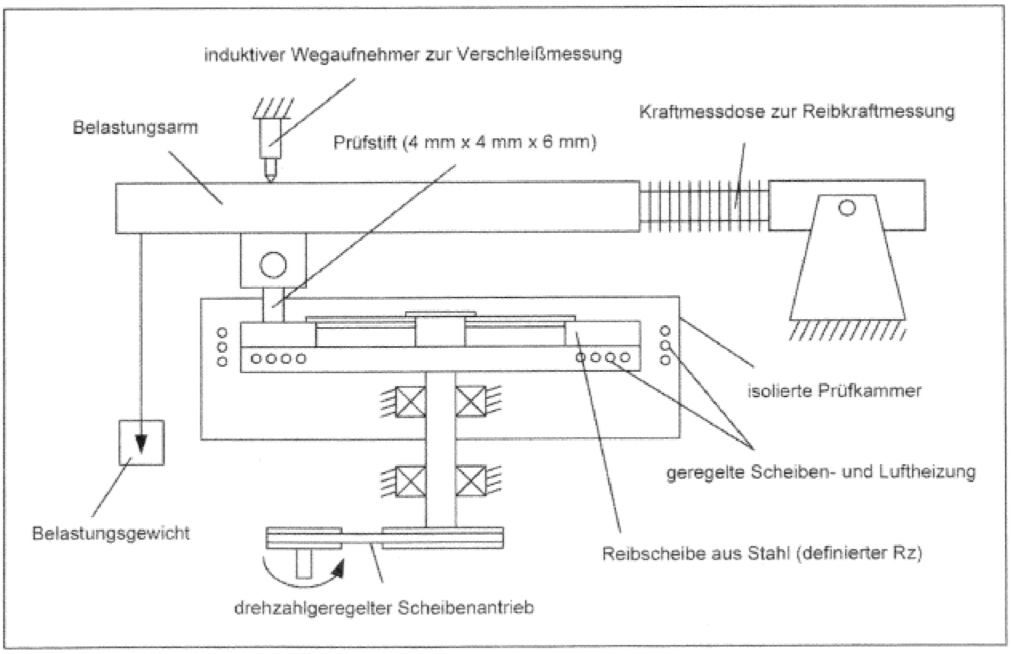
The main difference between the calculated and measured wear distribution is near the meshing point C (here at d=39 mm). The reason is, that the calculation of the wear progress should be simulated; therefore the wear should be calculated after 100 hours, then with the new (changed by wear) flank form, the calculation should be repeated, and so on.



Example: Blue = Wear calculated in one step after 10000 h
Green = Wear calculated in 5 steps of 2000 h
Red = Original flank

As the example here shows, using a step by step method is producing very accurate tooth wear forms. Actually, simulating this process is quite time consuming. It is planned to add this step by step process for the next KISSsoft release.

Important:
The comparison between measured and calculated wear gives good results. But the main question is, if the wear coefficient is measured precisely and if a wear coefficient measured on a thrust washer apparatus can directly be used for gear wear calculations. The comparison shown was based on a research by the University of Erlangen (Germany). They measured the wear coefficients on a brad-ring apparatus, which is more precise, because temperature on such an apparatus will remain constant after a short run-in time (compared to the thrust washer apparatus, where this is not always given).
Therefore results of wear calculations must be interpreted carefully, but even if they may not be very accurate (predicted life may be only +- 50% accurate), it is much more than what was possible to calculate in the past.



Brad-Ring Apparatus for Wear measurements