

KISSsoft Exercise 3

Bevel Gear 03

Sizing of a Face Hobbing hypoid gearset

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Sharing Knowledge

1 Purpose of exercise

In this exercise, we will design a Face hobbing bevel gearset, then change it into a hypoid gearset. It is an industrial application, lapped.

- Sizing of a new bevel gear set
- Selection of the size of cutter head and check the influence to the root strength
- Comparison of a bevel gear to a hypoid gear regarding strength and efficiency
- Optimization of hypoid gear set using fine sizing

2 Task

| Initial data: | |
|---------------------|-----------------------|
| Bevel type: | Face hobbing, lapped |
| Material: | 16 MnCr5 |
| Oil: | ISO VG 68, oil bath |
| Gear quality: | 8 as per ISO 17485 |
| Hand of spiral: | Pinion left hand (LH) |
| Rating standard: | ISO 10300:2014 |
| Power: | P = 24 kW |
| Speed (at pinion): | n = 3'000 upm |
| Required lifetime: | 5000 h |
| Operation mode: | Drive side |
| Application factor: | K _A = 1.1 |
| Mounting factor: | $K_{H\beta-be} = 1.1$ |

Manufacturing process: Ring gear non-generating

2.1 Step 1

Do a first sizing using the functionality "Rough sizing". Check the strength at the bevel gear set (without offset).

Sizing data:

The required safeties are $S_{Fmin} = 1.4$ and $S_{Hmin} = 1$.

| Transmission ratio: | 3.9 |
|---------------------|---------------------------|
| Gear set ratios: | $b/m_n = 10, R_e/b = 3.0$ |
| Spiral angle: | 30° |

Cutter head size: Sizing with ratio of involute / outer cone distance = 0.9

2.2 Step 2

Choose the cutter head from the list of ISO 23509. The smallest possible cutter head is to be preferred, due to the positive V/H (E/P) behavior and benefit to the root strength.

Compare the root safety SF in ISO 10300, if the bigger cutter head is taken instead of the smaller cutter head.

2.3 Step 3

Change the calculation to hypoid and add the offset. Define the blanks. Compare the strength and the blanks in 2D graph "System".

The offset is 15% of the ring gear outer diameter.

2.4 Step 4

Optimize the hypoid design with the "fine sizing" functionality. Check for an optimal solution with same ring gear diameter.

Sizing data:

Offset: between 10% and 25% of ring gear outer diameter

The focus of the optimization should be on pinion root strength and efficiency (method acc. to WECH). Second priority are high contact ratio (for noise) and low axial forces on pinion.

3 Solution

3.1 Step 1

Input of initial data

In tab "Basic data", select the following gear geometry settings:

| Basic data 🛛 🗗 | Pr | ocess | 8 | Referer | nce profile | e 🗗 | Manufac | turing | ć |
|--|-------------------|-------|------------|--------------|-------------|-------|---------|--------|---|
| Configuration | | | | | | | | | |
| Type Uniform depth, fig 3 (Face Hobbing, Klingelnberg) $\lor \diamond 0$ | | | | | | | | | |
| | | | | | | | | | |
| Normal pressure angle | a _n | | | | | 20.00 | 00 ° | | |
| Gear 1 | | heli | x left han | id (spiral t | eeth) | | \sim | ç | |
| Mean spiral angle Gear 2 | 2 β _{m2} | | | | | 30.00 | 00 ° | + | |
| | | | | | 7 | | _ | | |
| Quality (ISO 17485) | | Q | | 8 | | | 8 | | |

Figure 3.1-1 Choose "Uniform depth" in tab «Basic data», set hand of spiral and enter the gear quality number.

Select the gear material and use a lubricant as shown below:

| Material and | lubrication | | | | | |
|--------------|----------------------|---|--|---|----|---|
| Gear 1 | Case-hardening steel | | 16 MnCr 5 (1), case-hardened, ISO 6336-5 Figure 9/10 (MQ), Core hardness >=25HRC Jominy J=12mm <hr(<math="" display="inline">\sim</hr(> | • | b. | |
| Gear 2 | Case-hardening steel | | 16 MnCr 5 (1), case-hardened, ISO 6336-5 Figure 9/10 (MQ), Core hardness >=25HRC Jominy J=12mm <hr(<math="" display="inline">\sim</hr(> | • | ł. | |
| Lubrication | Oil bath lubrication | + | Oil: ISO-VG 68 | • | 2 | + |

Figure 3.1-2 Gear material and lubrication in tab «Basic data»

Define the load data and select the rating method in tab "Strength".

Note that the working flank is initially defined as right flank, which results in 'Coast' condition. Change the working flank gear 1 to 'left flank'.

| Basic data 🖻 Process | 🗗 Reference profile 🗗 Manufacturing 🗗 | Toleran | nces 🗗 Strength 🗗 × 🛛 Factors 🗗 |
|---|--|---------|--|
| Rating | | | |
| Driving gear | Gear 1 v | | Reference gear Gear 1 ~ |
| Working flank Gear 1 | left flank ~ | Ô | Reference speed $ n_1 $ 3000.0000 1/min \bigcirc |
| Sense of rotation, looking at tip of Gear 1 | Іеп | Ô | Reference torque T ₁ 76.3944 Nm |
| Operation | Drive side | | Reference power P 24.0000 kW ○ ↔ |
| Required service life | 5000.0000 h | ← - | + |
| Calculation method | | | |
| Factors, root, flank | Bevel gear ISO 10300:2014, Method B1 $\qquad \sim$ | ۶ | Subsurface fatigue DNV 41.2 ~ + |
| Scuffing | according to calculation method ~ | + | Reliability No calculation ~ |
| Tooth flank fracture | No calculation ~ | + | |

Figure 3.1-3 Select rating method ISO 10300:2014 B1, enter power and speed and set required life to 5000 h. Also change the working flank to 'left flank'.

In the tab "Factors", the application factor and mounting factor are defined.

| c data 🗗 🛛 Process 🗗 | Reference profile 🗗 | Manufacturing | 8 | Tolerances | 8 | Strength | ð× | Factors | Ð |
|--------------------------------------|-----------------------------|-------------------|--------|------------|-------|----------|-----|-----------|---|
| General factors | | | | | _ | | | | |
| Application factor | KA | | | | 1.100 | Q Q | Z-' | Y Factors | |
| Dynamic factor | Kv | | | | 1.000 | | | | |
| Transverse load factor | Кна | | | | 1.976 | 2 | | | |
| Mounting factor (Load distribution m | odifier) K _{Hβ-be} | | | | 1.100 | 0 © | | | |
| Figure 2.1.4 Cot mounting footor | 1 10 and the | application facto | ~ IZ . | 1 10 | | | | | |

Figure 3.1-4 Set mounting factor $K_{H\beta\text{-}be}$ = 1.10 and the application factor K_A = 1.10.

Before sizing of the bevel gear, the required safeties are to be entered.

Under 'calculation – settings' the required safeties are defined. For an easier display, the option 'Safeties are not depending on size' may be used.

| K Module specific settings | | | | | |
|--|------------------------|-----------------|------------------|----------|----------------|
| General Sizings Calculations Tooth form | Safety factors Differe | ntial gears Con | ntact analysis | Diagrams | 2D/3D geometry |
| General | | | | | |
| Configuration | | Safeties not d | lepending on siz | ze | ~ |
| Required safeties for metal (ISO/DIN) | | | | | |
| Root safety | S _{Fn} | in | | | 1.4000 |
| Flank safety | SHI | in | | | 1.0000 |
| Safety against scuffing (integral temperature) | Ssn | in | | | 1.8000 |
| Safety against scuffing (flash temperature) | S _{B n} | in | | | 2.0000 |
| Safety against tooth flank fracture | SFF | in | | | 1.2000 |

Figure 3.1-5 Enter the required safety factors in 'module specific settings'.

Now we start using the rough sizing function. Enter the required ratio and the mean helix angle at 30°, press "Calculate" and "Accept".

| K Rough sizing macrogeometry | | _ | | × | | |
|-------------------------------------|---------------------|----------|------|--------------|--|--|
| Transmission ratio | u | 3.9 | | | | |
| Ratio of facewidth to normal module | e b/m _{mn} | 10.0000 | | \leftarrow | | |
| Ratio of cone distance to facewidth | R _e /b | 3.0000 | | \leftarrow | | |
| Mean spiral angle Gear 2 | β_{m2} | 30.0000 | 0 | \leftarrow | | |
| Mean normal module | m _{mn} | 2.9414 | mm 🗆 | | | |
| Number of teeth, Gear 1 | Z1 | 11 | | | | |
| Facewidth Gear 2 | b ₂ | 30.1504 | mm 🗆 | | | |
| Outer pitch diameter Gear 2 | d _{e2} | 175.2588 | mm 🗆 | | | |
| Accept Calculate Cancel | | | | | | |

Figure 3.1-6 Use of rough sizing function to get a first proposal for the bevel gear set

You will see that the pinion number of teeth is reasonable (a reasonable range is e.g. 11-16). In the tab "Process", set up the manufacturing process for ring gear as formate (non-generating) and use the sizing button for the cutter head.

| Basic data 🗗 Process 🗗 | Reference profile 🗗 🛛 Manu | ufacturing | Tolerances | 8 | Strength 🗗 | × |
|--|----------------------------|------------|---------------------------|-------------------|------------|------|
| Manufacturing process | | | | | | |
| Gear 1 Gear 2 Gear 1 Gear 2 generate formate process | | | | | | |
| Manufacturer's data for spiral teeth | | | | | | |
| \Box Adopt data from Klingelnberg machines list | | Cutter | radius r _{c0} | 45.225 | 56 mm ← | € → |
| Manufacturing Face Hobbing (continuing inde | xing method) 🗸 🖓 | Numb | per of blade groups z_0 | 1.000 | 00 | |
| | | Cutter | r module mo | 3.200 | 00 mm 🗆 | |
| | | | | | | |
| K Convert cutter radius | | ? X | | | | |
| \odot Cutter radius according to r_{c0}/R_{m2} | | | | | | |
| \circledast Cutter radius according to involute/R_{e2} | | | | | | |
| Ratio involute/outer cone distance | 0.9000 | Ô | Cutton and the | - | 40.2070 | |
| Cutter radius r.o. | 49.2070 mm | | | r _{c0} | 49.2070 | nim |
| | | | Number of blade grou | ps z ₀ | 1.0000 | |
| | Accept Calculate | Cancel | Cutter module | m ₀ | 3.2000 | mm 🗆 |

Figure 3.1-7 Setting of manufacturing process and sizing of cutter head with ratio involute / outer cone = 0.9.

The strength results can be checked now. Due to the simplified sizing algorithm, deviations from the required safety values may show up.

| Results (basic calculation) | | | | | | |
|---|--------------------|------------|---------|--|--|--|
| | | | | | | |
| General | | | | | | |
| Transverse contact ratio | [ε _α] | 1.234 | | | | |
| Overlap ratio | [ε _β] | 1.387 | | | | |
| Operation mode | Drive side | Drive side | | | | |
| | | | | | | |
| Components | | Gear 1 | Gear 2 | | | |
| Outer tip diameter (mm) | [d _{ae}] | 52.984 | 176.090 | | | |
| Root safety | [S _F] | 2.336 | 1.979 | | | |
| Flank safety | [S _H] | 0.997 | 1.040 | | | |
| Safety factor for scuffing (flash-temp) | [S _B] | 4.118 | | | | |
| | | | | | | |

Figure 3.1-8 Bevel gear safety factors after rough sizing.

See file Exercise-Bevel-03-sizing_hypoid_face_hobbing-v2200-jl-public_Step-1.Z70

3.2 Step 2

The cutter head size is the nominal radius, on which the blades of the tool are arranged. They come with standard sizes.



Figure 3.2-1 Face Hobbing cutter head. Radius is defined from center to the cutting edge of the blade.

In tab "Process", the info graphic for the tools according to the ISO 23509 is available.

| Face Hobbing | | | | | | |
|---------------------------------------|---|--|--|--|--|--|
| Two-bla (outer and inner | de cutter blade per group) | Face Milling | | | | |
| Cutter radius r _{c0} , mm | Number of blade groups, z ₀ | Cutter diameter, 2·r _{co} , in | | | | |
| 30 | 7 | 2.50 | | | | |
| 51 | 7 | 3.25 | | | | |
| 64 | 11 | 3.50 | | | | |
| 64 | 13 | 3.75 | | | | |
| 76 | 7 | 4.375 | | | | |
| 76 | 13 | 5.00 | | | | |
| 76 | 17 | 6.00 | | | | |
| 88 | 11 | 7.50 | | | | |
| 88 | 17 | 9.00 | | | | |
| 88 | 19 | 10.5 | | | | |
| 100 | 5 | 12 | | | | |
| 105 | 13 | 14 | | | | |
| 105 | 19 | 16 | | | | |
| 125 | 13 | 18 | | | | |
| 150 | 17 | / | | | | |
| 175 | 19 | / | | | | |
| | | mm | | | | |
| | | 500, 640, 800, 1000 | | | | |

Figure 3.2-2 Available cutter radius of standardized cutter heads

We choose the smallest possible cutter due to the centralized contact pattern behaviour under load.

| Cutter radius | r _{c0} | 51 mm | \leftarrow | \leftrightarrow |
|-----------------------|-----------------|-----------|--------------|-------------------|
| Number of blade group | Z ₀ | 7 | | |
| Cutter module | m ₀ | 3.2000 mm | | |

Figure 3.2-3 Enter the cutter radius and the number of blades in tab "Process".

With this we have finalized the design and manufacturing of a bevel gear set (not a hypoid yet). Rerun the calculation to find:

| Results (basic calculation) | | | |
|---|--------------------|--------|---------|
| | | | |
| General | | | |
| Transverse contact ratio | [ε _α] | 1.2 | 234 |
| Overlap ratio | [ε _β] | 1.3 | 387 |
| Operation mode | Drive side | | |
| | | | |
| Components | | Gear 1 | Gear 2 |
| Outer tip diameter (mm) | [d _{ae}] | 53.994 | 179.447 |
| Root safety | [S _F] | 2.459 | 2.083 |
| Flank safety | [S _H] | 0.996 | 1.039 |
| Safety factor for scuffing (flash-temp) | [S _B] | | 3.919 |

Figure 3.2-4 Gear rating results with above manufacturing data.

See file Exercise-Bevel-03-sizing_hypoid_face_hobbing-2200-jl-public_Step-2.Z70

3.3 Step 3

We now compare a bevel gear set with a hypoid gear set. For the current bevel design, we find the efficiency according to calculation method "Wech". To calculate the efficiency of the bevel gear set with the method "Wech", we deactivate the scuffing calculation and select the method "Wech" in the module specific settings.

| 14.2 Gear power loss and coefficient of frie | ction | |
|--|------------------------------|--------|
| | | |
| Calculation according to | Wech | |
| Coefficient of friction | [µm] | 0.073 |
| The coefficient of friction μ_m can vary deper | nding on calculation method. | |
| Compound velocity (m/s) | [νΣ] | 6.951 |
| Loss factor | [iiv] | 0.100 |
| Gear power loss (kW) | [PVZ] | 0.314 |
| Meshing efficiency (%) | [ŋz] | 98.691 |
| | | |

Figure 3.3-1 Report, information on efficiency, for bevel gear set

Now we enter an offset of 15% (here 27 mm) to calculate a corresponding hypoid gear set. We now observe a massive increase in root safety due to the hypoid offset. Due to the increased diameter of the pinion, lower forces result.

| | | Gear 1 | Gear 2 | [| Deta | ils |
|-------------------------------------|------------------|---------|---------|----|--------------|-------------------|
| Number of teeth | z | 11 | 43 | | | |
| Facewidth | b | 37.0000 | 30.7253 | mm | | |
| Profile shift coefficient | X _{hmn} | 0.4300 | -0.4300 | | \leftarrow | \leftrightarrow |
| Tooth thickness modification factor | X _{smn} | 0.0650 | -0.0650 | | | |
| Quality (ISO 17485) | Q | 8 | 8 | | ۶ | |
| Shaft angle | 2 | | 00.000 | 0 | | |
| Hypoid offset | а | | 27.0000 | mm | | |

Figure 3.3-2 Enter the hypoid offset of 27mm.

| Calculation method | | | |
|----------------------|--|---|---|
| Factors, root, flank | Hypoid gears ISO 10300:2014, Method B1 | ~ | ۶ |
| Scuffing | 130/13 10300-20.2021 | ~ | + |
| Tooth flank fracture | No calculation | ~ | + |

Figure 3.3-3 Change the calculation method in the tab 'strength' from bevel results for hypoid gear set.

| Results (basic calculation) | | | |
|--|--|------------------------------------|-------------------------------------|
| General | | | |
| Transverse contact ratio | [8-] | 1 | 080 |
| Overlap ratio | [20] | 1. | 682 |
| Operation mode | Drive side | | |
| | | | |
| | | | |
| Components | | Gear 1 | Gear 2 |
| Components Outer tip diameter (mm) | [d _{ae}] | Gear 1 75.106 | Gear 2 180.137 |
| Components Outer tip diameter (mm) Root safety | [d _{ae}] [S _F] | Gear 1 75.106 4.687 | Gear 2 180.137 3.889 |
| Components Outer tip diameter (mm) Root safety Flank safety | [d _{ae}] [S _F] [S _H] | Gear 1 75.106 4.687 1.567 | Gear 2 180.137 3.889 1.634 |

Figure 3.3-4 Increased safety numbers for hypoid gear set for root bending strength and contact stress.

In the 2D system graphics we can now clearly see the increased size of the pinion:



Figure 3.3-5 Increased pinion size for hypoid gear set.

The hypoid gear shows a drop in efficiency and the scuffing safety (see report):

| 14.2 Gear power loss and coefficient of frictio | n | |
|--|--------------------------|--------|
| | | |
| Calculation according to | Wech | |
| Coefficient of friction | [µm] | 0.027 |
| The coefficient of friction μ_m can vary depending | g on calculation method. | |
| Compound velocity (m/s) | | 0.046 |
| Gear power loss (kW) | [PVZ] | 0.456 |
| Meshing efficiency (%) | [ŋz] | 98.101 |
| | | |

Check the influence factor of limit pressure angle under additional data.

| Geometry | | | | | | | |
|----------------------|--------------------------|------------------------------|-------------------|----------|------------|-----------------|--|
| Mean normal modul | e m _{mn} | | : | 3.0423 r | nm 🤇 | \rightarrow C | |
| Outer pitch diameter | r Gear 2 d _{e2} | | 178 | 8.6005 n | nm 🦉 | 0 | |
| Normal pressure and | gle a _n | | 2 | 0.0000 ° | , | + | |
| Gear 1 | K Additional data for | hypoid gears | | | ? | × | |
| Mean spiral angle G | Pressure angle o | n drive side | a _{dD} | 20.000 | 00 ° | | |
| Angle modification (| Pressure angle o | n coast side | 0.10 | 20.000 | <u>0</u> 0 | | |
| | Influence coeffic | ient for limit pressure angl | f _{alim} | 1.000 |)0 | | |
| | | | (| Ж | Canc | el | |

Figure 3.3-6 Input of influence coefficient of limit pressure angle under 'additional data for hypoid gears'

Also, check the several pressure angles such as 'design (nominal) pressure angle', 'generated pressure angle' and 'effective pressure angle' in the report.

| 5.2 Basic data | | |
|---|--------|---------------|
| | | Gear 1 Gear 2 |
| No modification at tip circle | | |
| Overall transmission ratio | [itot] | -3 909 |
| Gear ratio | [u] | 3.909 |
| Nominal pressure angle - drive side (°) | [αdD] | 20.0000 |
| Nominal pressure angle - coast side (°) | [adC] | 20.0000 |
| Limit pressure angle (°) | [alim] | -1.3577 |
| Generated pressure angle - drive side (°) | [ɑnD] | 18.6423 |
| Generated pressure angle - coast side (°) | [anC] | 21.3577 |
| Effective pressure angle - drive side (°) | [aeD] | 20.0000 |
| Effective pressure angle - coast side (°) | [aeC] | 20.0000 |

Figure 3.3-7 Report, information on pressure angles

See file Exercise-Bevel-03-sizing_hypoid_face_hobbing-v2200-jl-public_Step-3.Z70

3.4 Step 4

Use the fine sizing function e.g. as shown below. Set parameters as considered suitable and run the fine sizing function:

| Fine sizing macrogeometry | | | | | | _ | |
|----------------------------------|----------------------|------------------|------------------|-----------|------|---------|--------------|
| Conditions I Conditions II | Conditions III Posu | lts Graphic | | | | | |
| Conditions 1 | Conditions III Resul | its Graphic | | | 1 | | |
| Maximum number of solutions | ; | | | 2000 | | | |
| Nominal transmission ratio | i | | | 3.9000 | | | |
| Deviation from nominal ratio | Δi | | | 5.0000 | % | | |
| Input | | Outer pitch diam | eter Gear 2 | ~ | | | |
| | | Minimum | Maximum | Step | | | |
| Outer pitch diameter Gear 2 | d _{e2} | 178.6005 | 178.6005 | 0.0000 | | | |
| Normal pressure angle | a _n | 19.0000 | 21.0000 | 1.0000 | 0 | | \checkmark |
| Mean spiral angle Gear 2 | β _{m2} | 25.0000 | 35.0000 | 5.0000 | • | | \checkmark |
| Facewidth Gear 2 | b ₂ | 30.7253 | 30.7253 | 0.0000 | mm | | |
| Profile shift coefficient Gear 1 | Xhmn1 | | | 0.0000 |] | | |
| Hypoid offset | a | 17.0000 | 44.5000 | 5.0000 | mm | | \checkmark |
| Number of teeth, Gear 1 | Z ₁ | 9 | 14 | 1 | | | \checkmark |
| | | Gear 1 | | Gear 2 | | | |
| Fix number of teeth | z | | 10 | 37 |] | | |
| Update fine sizing inputs | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | A | ccept Contact a | analysis Calcula | te Delete | Save | Restore | Clos |

Figure 3.4-1 Possible input data for fine sizing functionality.

We find a high number of possible solutions. We use the graphical representation of the solutions to compare the efficiency and root strength of pinion depending on the hypoid offset.



Figure 3.4-2 Minimum root and flank safety are shown, depending on the varying number of teeth on pinion.

Look at (as a function of offset, number of teeth on pinion, etc.)

- Efficiency
- Flank strength
- Gear (and hence bearing) forces (radial and axial, typically pinion bearings are more critical)

It is up to the design engineer to now select a suitable solution.

See file Exercise-Bevel-03-sizing_hypoid_face_hobbing-v2200-jl-public_Step-4.Z70