KISSsoft AG - ☏ +41 55 254 20 50
Uetzikon 4 - 🖷 +41 55 254 20 51
8634 Hombrechtikon - info@KISSsoft.AG
Switzerland - www.KISSsoft.AG

Bevel Gear Differential, Overlaid Shafts and Pocket Bearings

1 Description

1.1 Task

The Modelling of a bevel gear differential may appear in a first approach difficult, even impossible for a new KISSsys user, because of power split, interaction between outputs and maybe overlaid shafts with pilot bearings. All these systems can be modelled though. That modelling requires certain proceedings and methods which this paper should explain. The following tasks are described in this paper

1. The modelling of bevel gear differentials
2. The modelling of overlaid shafts
3. The modelling of pocket/pilot bearings

Because of the large variation of the differential designs all special things cannot be described here. In case if you need some more instructions, please contact KISSsoft AG and ask for KISSsys support.
You may also review the corresponding KISSsys model "Bevel-gear-differential-large.ks"

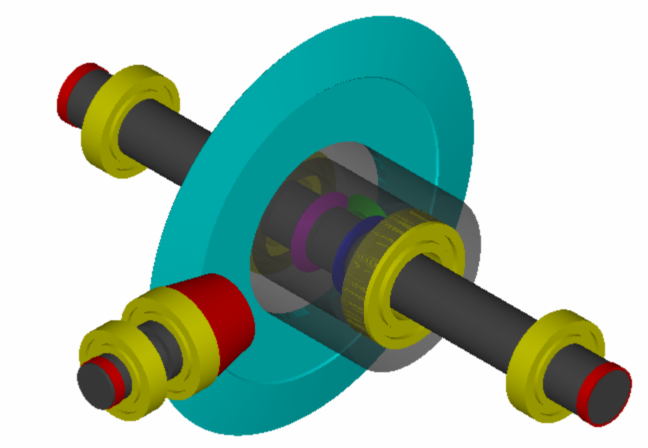

Figure 1.1-1 KISSsys 3DView of the example model

1.2 Schematic

The example model enables to describe these three above problems all in one model:

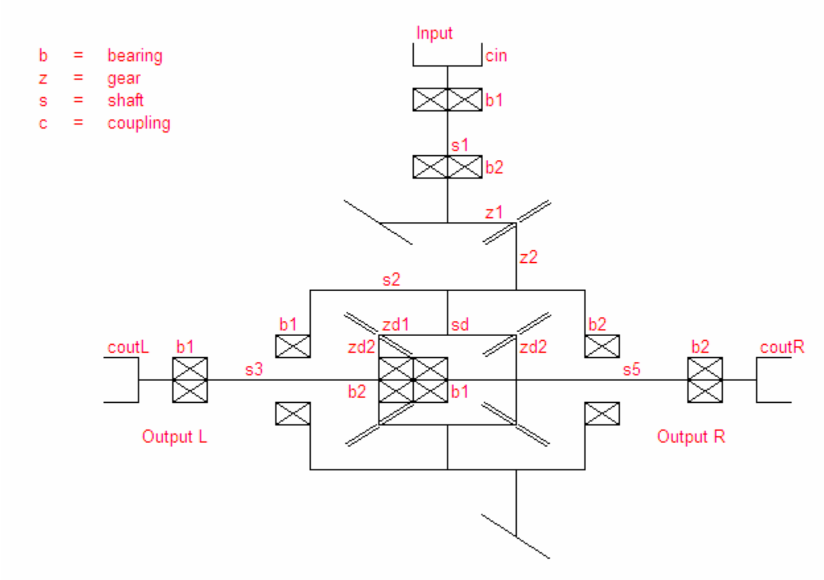

Figure 1.2-1 Schematic of the example model

2 Modelling

In order to be able to model the correct tree structure the systematic modeling of the above mentioned problems has to be explained.

2.1 Overlaid Shafts and Pocket Bearings

The current problem contains shaft “s2” which is supported by the two shafts “s3” and “s4” (overlaid shafts). In their turn they have each a fixed bearing on the casing, “s4” is assembled in “s3” and two bearings (pilot bearings) between the bore of “s4” and the outside diameter of “s3” guarantee that a different movement and rotation of the two shafts is possible. Of course shafts “s4” and “s3” can also be arranged other way round.

The problem is now the modeling of the force interaction between the three shafts. Just as an example: The gear force on “z2” has to be supported by the shaft “s2” and its bearings, therefore by “s3” and “s4”. In its turn, the deflection of “s3” and “s4” will influence the bearings alignment of “s2”. Therefore KISSsoft AG suggests modeling the interaction between these three shafts as follows:

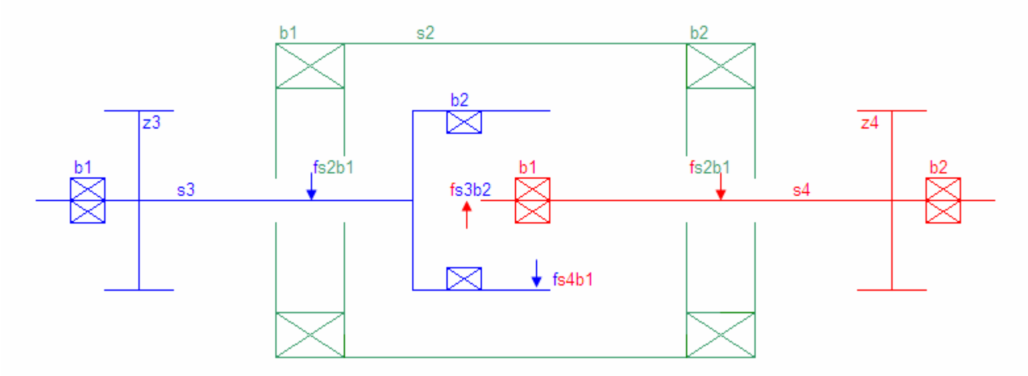

Figure 2.1-1 Interaction between overlaid shafts

As indicated by the colors in Figure 2.1-1 the action force “fs2b1” on “s3” is dependant on the bearing force coming from “b1” on “s2”. In return, the “fs2b1” returns the current deflection of “s3” to “b1” on “s2”. As it is possible to enter bearing misalignments in KISSsoft this value can also be taken into account.

2.2 Modelling with Standard Templates

2.2.1 Forces

The modelling of the interaction between action force and bearing is shown as an example between "fs2b1" and "b1". Enter the address of the bearing forces into the expression of the centrical force (example: Fx) to link the force values to the bearing.

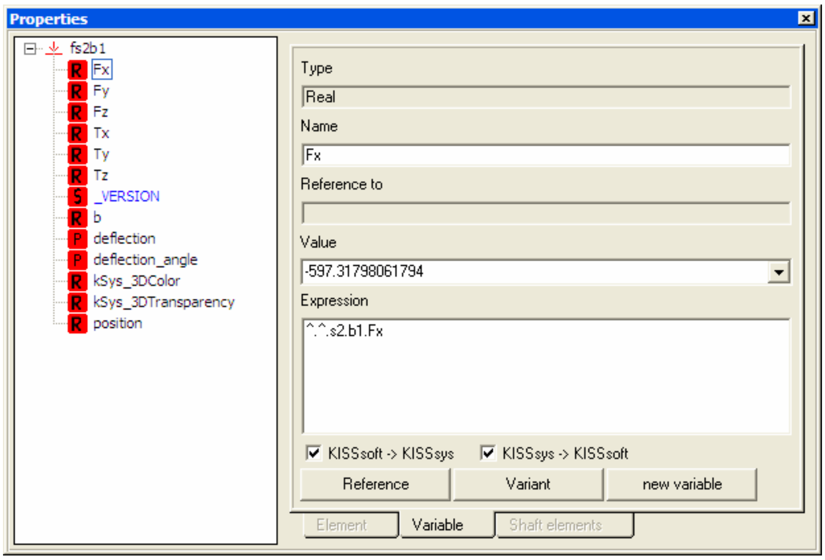

Figure 2.2-1 Defining force from the bearing

Centrical Force Variable	Expression
Fx	^.^.s2.b1.Fx
Fy	^.^.s2.b1.Fy
Fz	^.^.s2.b1.Fz

Hint: The sign ^ goes one level up in the three structure and gives the path until this level.
Example: ^.^.s2.b1.Fx = GB.s2.b1.Fx
The sign is useful, because you do not have to think less about the address of your variables and renaming after model building is less of a problem.

2.2.2 Deflection

Enter the deflection of the shaft where the centrical load is situated (s3) as offsets (ux, uz) into the bearing element.

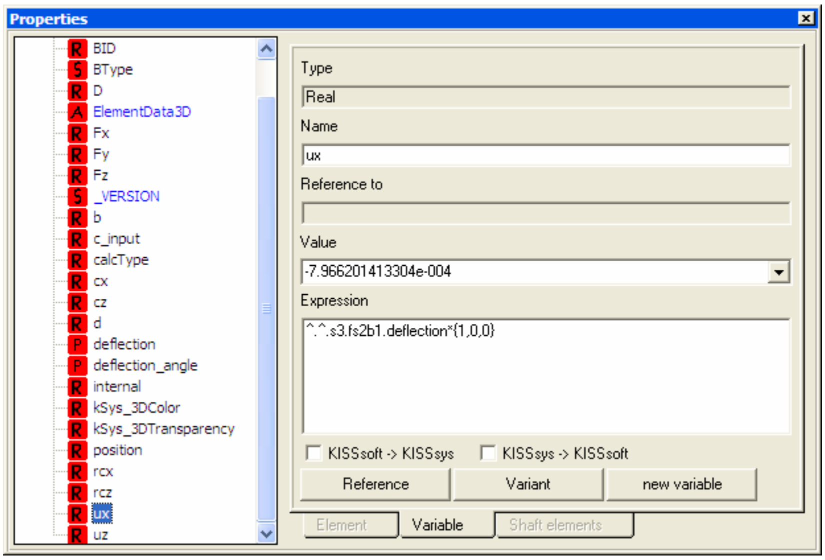

Figure 2.2-2 Bearing offset equals to shaft deflection

As the deflection of the shaft is given in a variable of type point and the bearing offset is given as real. It is possible to take out coordinates of points by multiplying them with the axis you need:

Bearing Variable	Expression
ucx	^.^.s3.Fs2b1.deflection*{1,0,0}
ucz	^.^.s3.Fs2b1.deflection*{0,0,1}

2.2.3 Positioning the force

As a last point the force has to be positioned correctly by hand or you may create expression between bearing position and force position. If bearing is moved on the shaft force will be automatically repositioned according to the bearing, because the bearing "b1" and the corresponding force "fs2b1" needs to be on the same position in the space. We can create an expression for the force position, so that it will always be positioned according to the bearing. This can be done under "Properties"- "position" of the force "fs2b1".

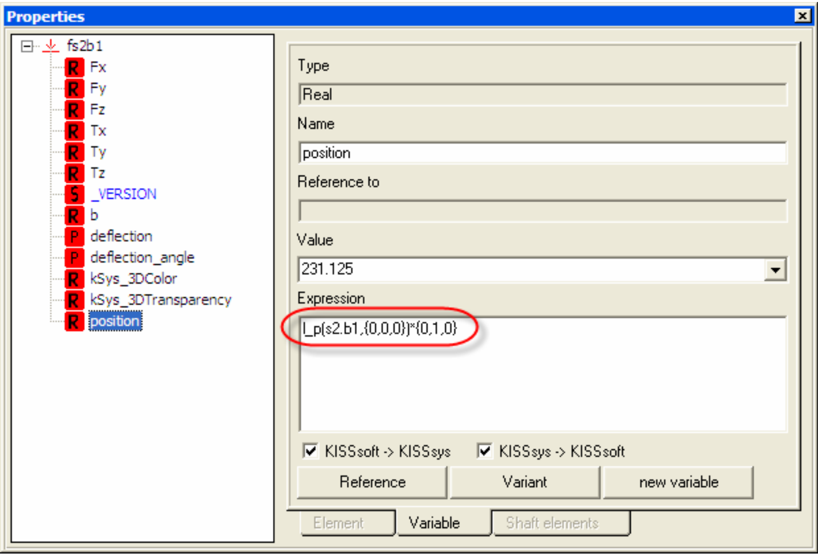

Figure 2.2-3 Position of the force

Using the function "l_p(reference,{point})*{0,1,0}" it is possible to transform the local coordinate of the "reference" component to the local coordinate of the parent component of the current component. So taking the local coordinate of the "b1" on the shaft "s2" and transforms it to the local coordinates to of the "fs2b1" on the shaft "s3". And finally multiplication with {0,1,0}takes only the y-component.

2.2.4 Notes

Please pay attention to following points when using standard templates. The orientation and direction of the centrical force and the bearing offset have to be identical on both elements. The coordinate systems of the two elements may not be oriented identical therefore the user has to spend some thoughts about the orientation topic.

2.3 Modelling with Special Templates

KISSsoft AG has developed special templates to make previously described connections easier. These templates are also available for our clients. The special templates do the above mentioned steps for force and deflection linkage automatically. See also instructions "ins-303-01-Pilot-bearing.pdf" for the issue.

1. Open the template file "SpecialTemplates.ks"
2. Enter the element "RollerBearingWithDeflections" instead of the normal "kSysRollerBearings" for the pilot bearings into your tree structure.
3. Enter the element "CentricalLoadWithBearingForces" instead of the normal "kSysCentricalLoad" for the forces into your tree structure
4. Open the "ForceSelection" of the bearings you entered and choose the linked force.

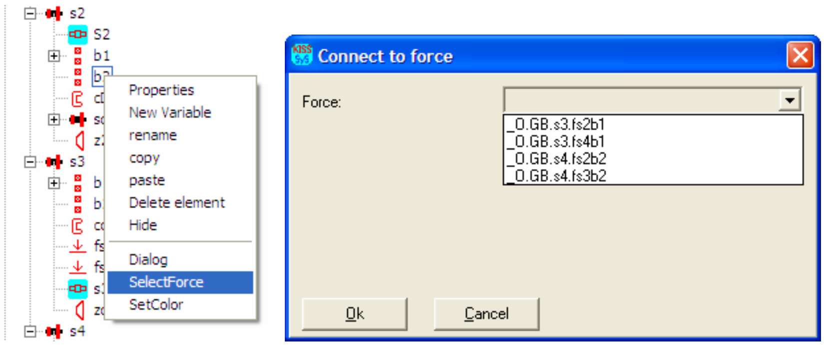

Figure 2.3-1 Choose the connected force

Please pay attention to following points when using the special templates. The positioning and orientation of the elements is correctly translated from one coordinate system to the other, so you do not have to bother with that. This requires though a correct global positioning of the entities.

2.4 Pilot bearing Calculations

2.4.1 Using standard bearing calculations

The bearing calculation is always taking the global speed of the shaft where the bearing is situated on. This does not apply when the inner ring and the outer ring are both turning. Then the rotation speed of the bearing has to be modified in order to take this into account (example "s2b1"):

$$n_{s2b1} = |n_{s2} - n_{s3}|$$

Default expression for the bearing speed can be deleted and it needs to be replaced with new expression to get relative speed between the shafts "s2" and "s3". Expression is "abs(GB.s2.speed-GB.s3.speed)".

This leads also to the problem, that the speed of the first and the second bearing on every of those 3 shafts (s2, s3 and s4) is different. Therefore you have to insert instead of the calculation element "Bearing2" the element "Bearing1". It is recommended to insert it under the machine element bearing.

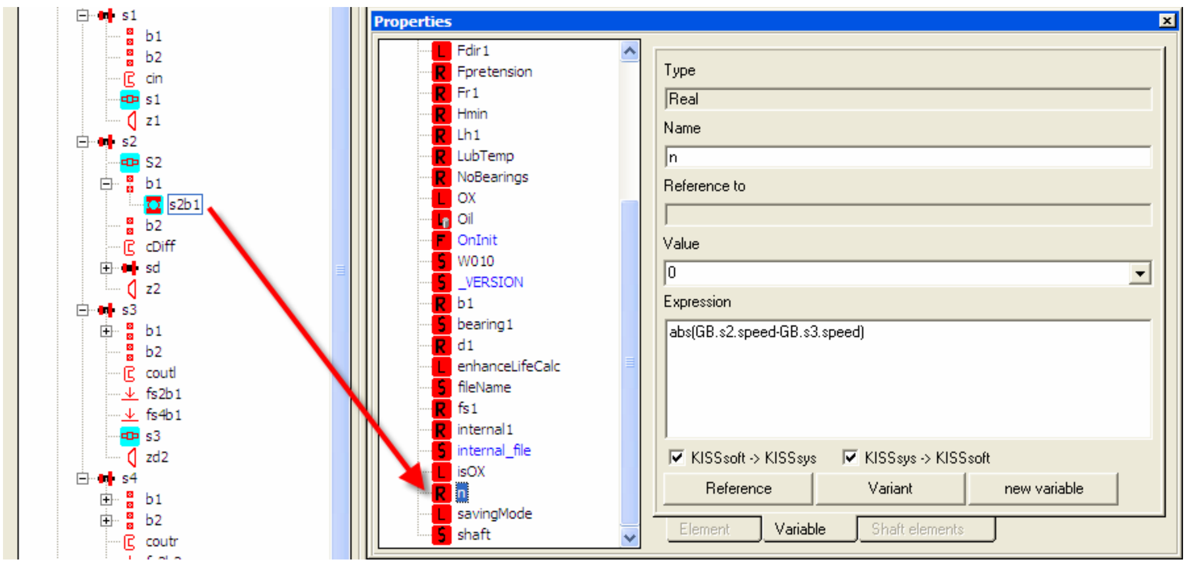

Figure 2.4-1 Bearing speed correction

2.4.2 Using special templates

KISSsoft AG has developed special templates to make previously described "pilot" bearing speed definition automatically. These templates are also available for our clients. The special templates do the above mentioned steps for the speed correction automatically.

1. Open the template file "SpecialTemplates.ks"

2. Enter the element “Pilot_Bearing1” instead of the normal “Bearing1” for the pilot bearings into your tree structure.
3. “Dialog” to select references is automatically opened.
4. If you want to change definitions, open the “Dialog” of the bearing calculation and choose new references.

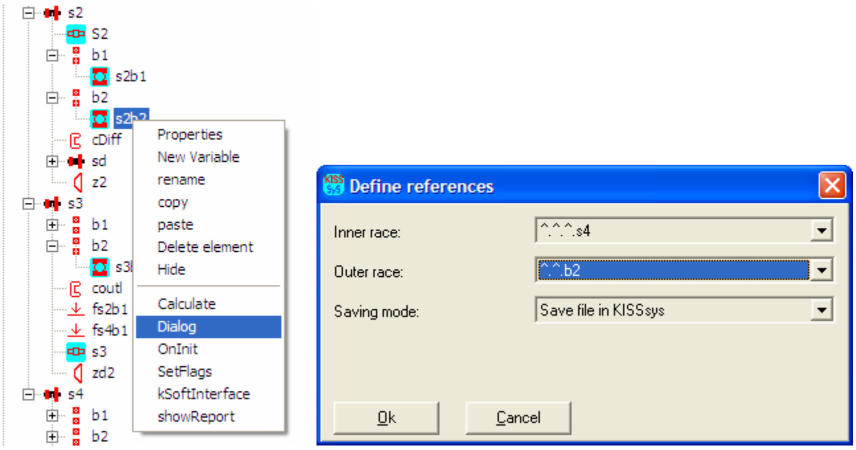

Figure 2.4-2 Defining references for the bearing inner and outer race

2.5 Example model

Both of the explained methods has been used in the related example model “Bevel-gear-differential-large.ks”. Connections between “s2” and “s3” are created using default templates “templates.ks” and connections between shafts “s2 and “s4” are made with using “SpecialTemplates.ks”.

2.6 Kinematics Iteration

As the bearing forces are in this case affecting deflection of the shaft and the deflection of the shaft in return is affecting the bearing forces, iterations have to be made when calculating the correct forces. These iterations are not activated per default.

To activate iterations, right click on “System” and choose “Properties”. Check the variable “kSysKinematicFunc”. Select from the list the functionality “call ‘OnCalcTorque’ during calculation of torque” and quit the window.

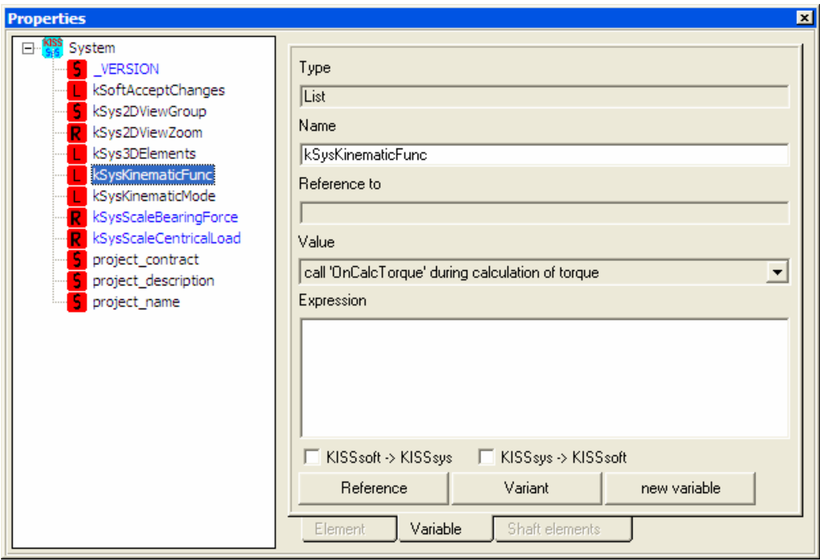

Figure 2.6-1 Setting the kinematic iteration

Be informed that you see the iteration steps now in the message bar in the lower section of the KISSsys window when you are calculating kinematics and that the calculation itself takes longer.

The iterations are for the speed and torque not activated as per default. To activate iterations, right click on “System” and choose “Properties”. Check the variable “kSysKinematicMode”. Select “iteration for speed and torque” from the list. The model may work correctly even without this iteration method, but when model gets more complicated this iteration is needed.

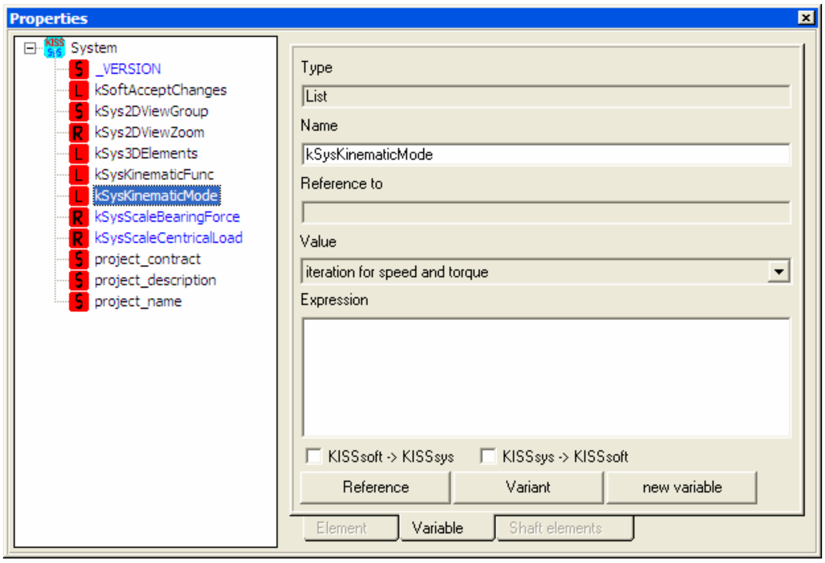

Figure 2.6-2 Select iteration method for the kinematic calculation

2.7 Model specialties

The following chapters explain special arrangements needed for the differential modelling.

2.7.1 “Carrier” definition

You need one extra component to the model to tell the program how differential gears are connected to the housing and which shaft is the differential housing and also how many differential planets are in the model. To do this, use “kSysPlanetCarrierCoupling” from the templates. This component defines the configuration of the differential.

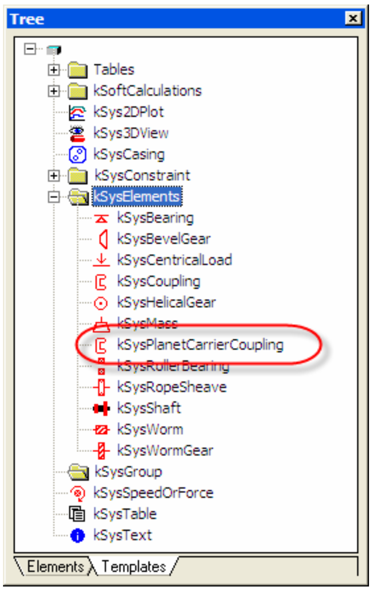

Figure 2.7-1 Differential carrier component

After you have places this component in to your model on your differential housing “s2” you can define number of planets in differential by selecting “properties” for that component and changing the value for the variable “NofPlanets”. If you change the number of the planets you need to “updateShaftElements” to consider new number of the planets for the calculations.

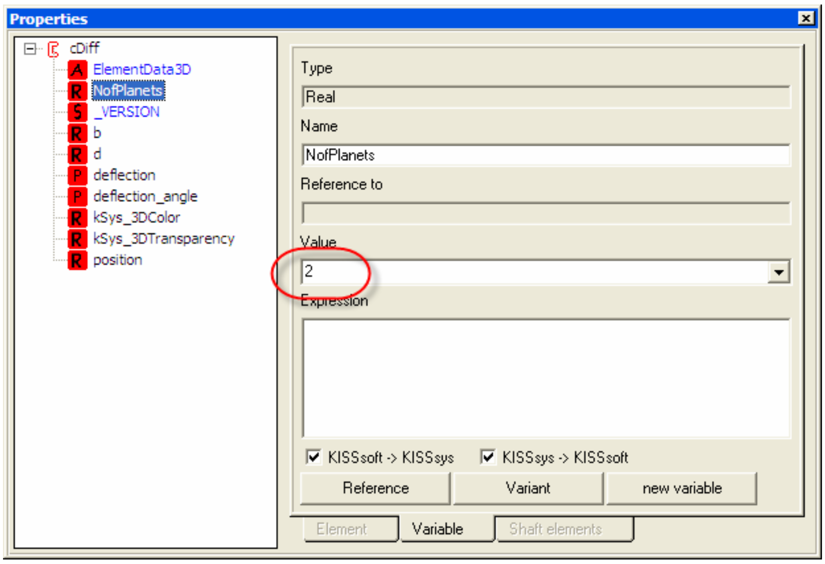

Figure 2.7-2 Changing the number of differential planets

Note! In case if you are using old templates where this component is not present, you can use "kSysCoupling" component instead and add needful information in it. Create new variable "NofPlanets" in the component and it has the same functionality. Remember to add flags for both directions.

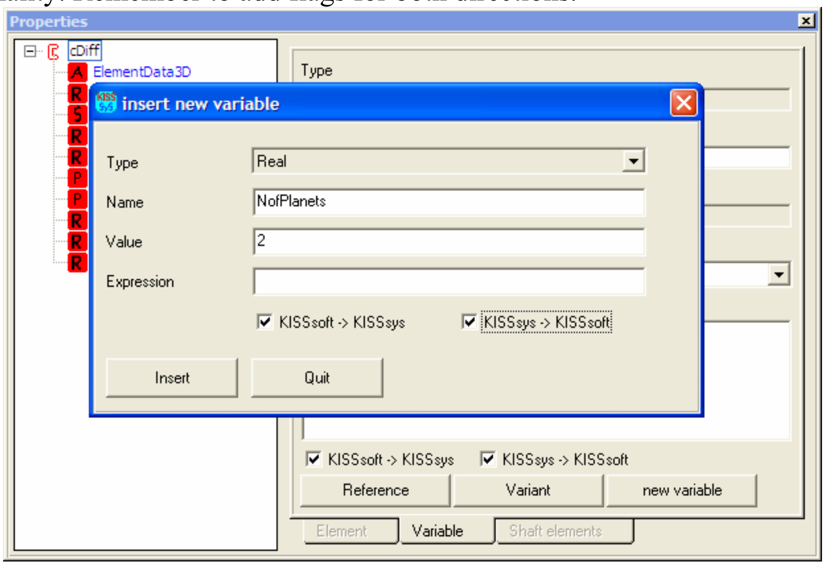

Figure 2.7-3 If using "kSysCoupling" add a new Real variable called "NofPlanets"

2.7.2 Differential gear connections

Use " kSysPlanetaryBevelGearConstraint" to define connections between differential bevel gears. You need to define first configuration from the list "gear/planet" or "planet/gear". First gear in the definition is the "gear 1" and second is the "gear 2". You need to make the selection so that the first gear has less number of teeth. From the configuration "gear" means the output gear and "planet" means the gear connected to the differential housing. You need to also define which coupling is the "planet carrier". The layout of the machine elements in the tree structure is very similar to a planetary gear stage ("cDiff" is in this case the carrier coupling). To constrain the differential system, choose the "kSysPlanetaryBevelGearConstraint" from the templates and copy it into the tree structure directly under the group of your model. Constrain the gears as follows.

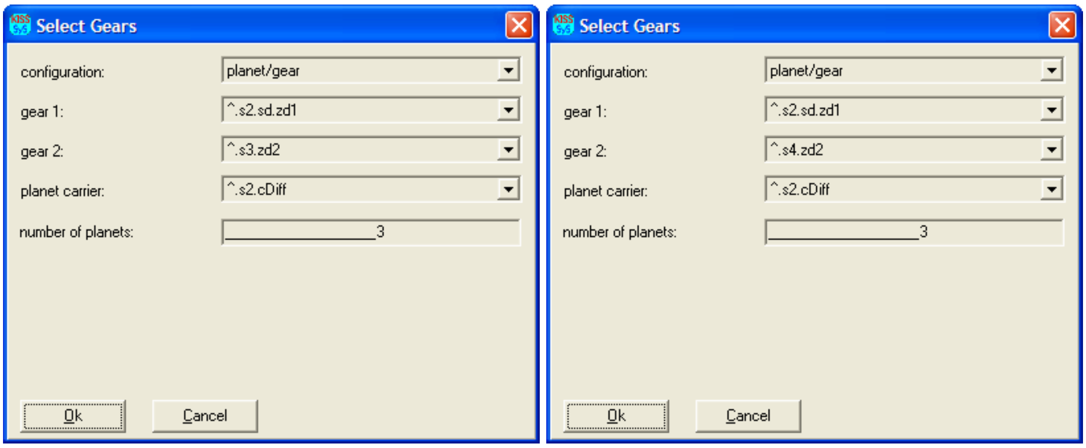

Figure 2.7-4 Choose differential gear connections

3 Gear positioning

3.1 Positioning according to bevel gears

To be able to make “kinematic” calculation user needs to define correct directions and positions of the output shafts in the space, because otherwise it is not possible to define output speeds and torques to the correct directions and error in “kinematic” calculation will appear. Differential gears needs to be therefore be defined according to each other, so that correct speeds can be defined for all the shafts.

It is recommended to define first the position of the differential housing “s2”. Then define other of the outputs “s3” or “s4” to be parallel to the “s2”. Then define differential planet “sd” position according to the differential gear meshing with gear in the defined shaft and finally define the direction and position of the other shaft meshing with the differential planet gear. Use dialog for all shaft to make the positioning

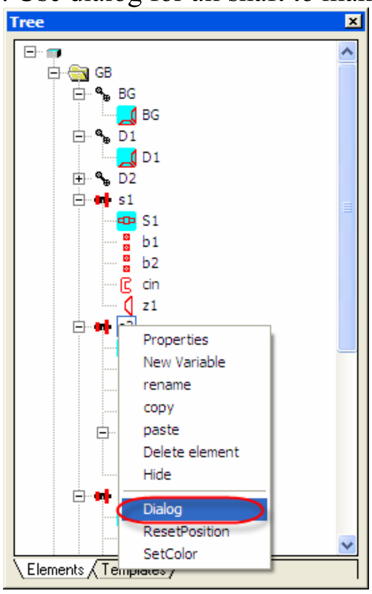

Figure 3.1-1 Choose "dialog" function from the tree to define position for the shafts

For the bevel gear connection choose “According Bevel Gears” from the list

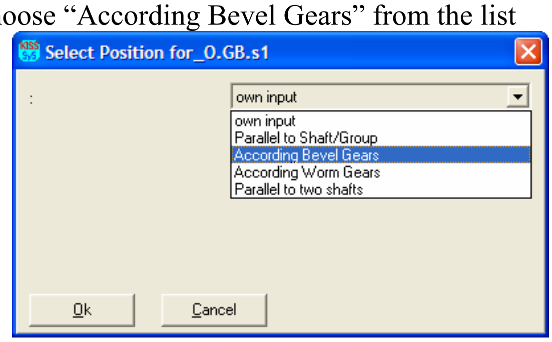

Figure 3.1-2 Choose correct positioning method from the list

1) Define the position of the “s2” “According Bevel Gears”. Select mating gear and define also correct contact angle.

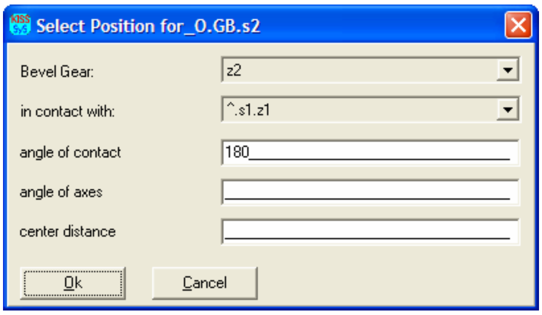

Figure 3.1-3 Positioning of the shaft "s2" according to the bevel gear mesh “z2” and “z1“

2) Define “s4” position to be parallel to “s2”

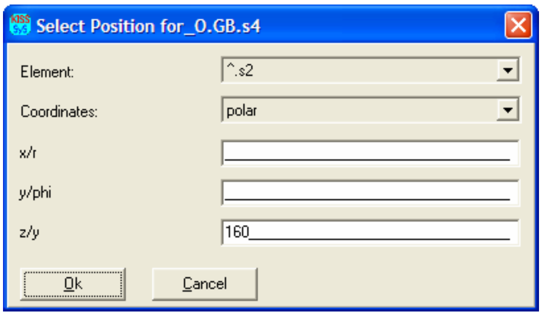

Figure 3.1-4 Right output "s4" defined parallel to differential housing "s2"

3) Define differential planet “sd” according to mating bevel gear in shaft “s4”

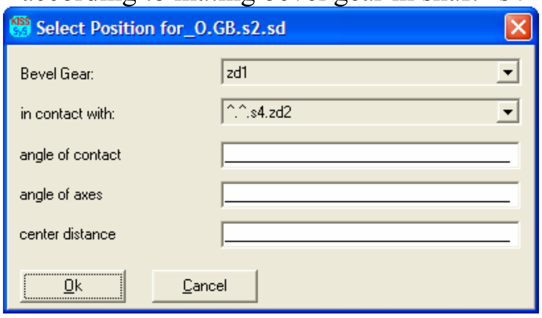

Figure 3.1-5 Planet shaft defined according to bevel gear mesh

4) Finally define direction and position of the left output “s3” according to bevel gear mesh with planet gear.

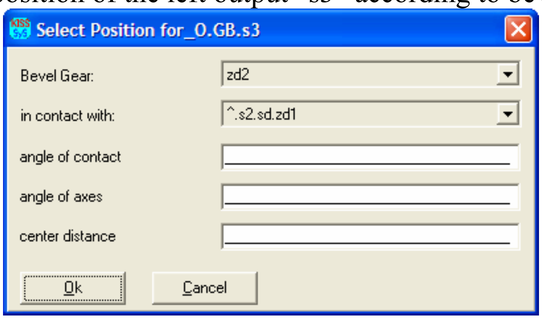

Figure 3.1-6 Left output "s3" defined according to bevel gear mesh

4 Boundary conditions

4.1 Input

Because there are six conditions to define for inputs and outputs (speed + torque/power), we need to define three of them to be able to run calculation. Speed and torque definition of a bevel gear differential has to be made correctly and usually Input is totally defined and output is then calculated.

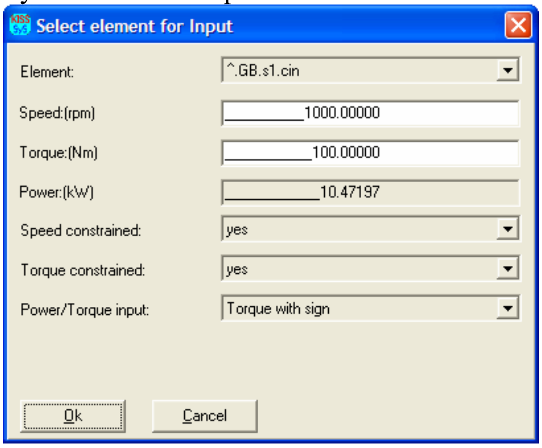

Figure 4.1-1 Input fully constrained

4.2 Outputs

That leaves the state of the two outputs undefined. One used option would be the definition of the speed of one differential output (example: s3) related to the casing speed with a factor k:

$$k = \frac{n_{s3}}{n_{s2}}$$

This makes it possible to define a formula for the calculation of the left output speed in our model as follows:

$$n_{outl} = n_{s3} = kn_{s2}$$

Definition of the output in the example model has to be made as follows:

1. Definition of global variable k
2. Setting the “kSysSpeedOrForce” element of the left output to “Speed constrained: yes”
3. Entering the expression for the correct speed calculation into the variable “speed” of the “kSysSpeedOrForce” element of the left output.

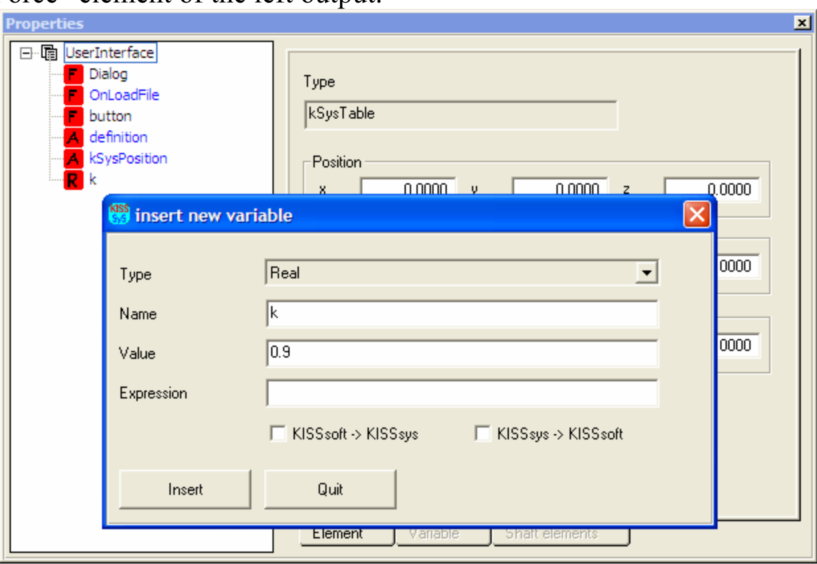

Figure 4.2-1 Define new variable "k"

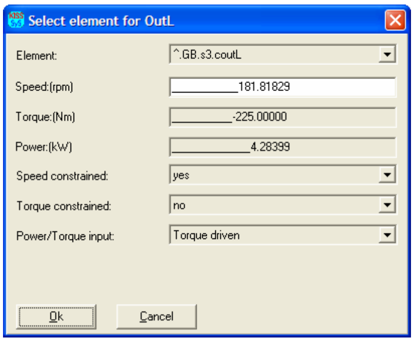

Figure 4.2-2 Constrain the speed value

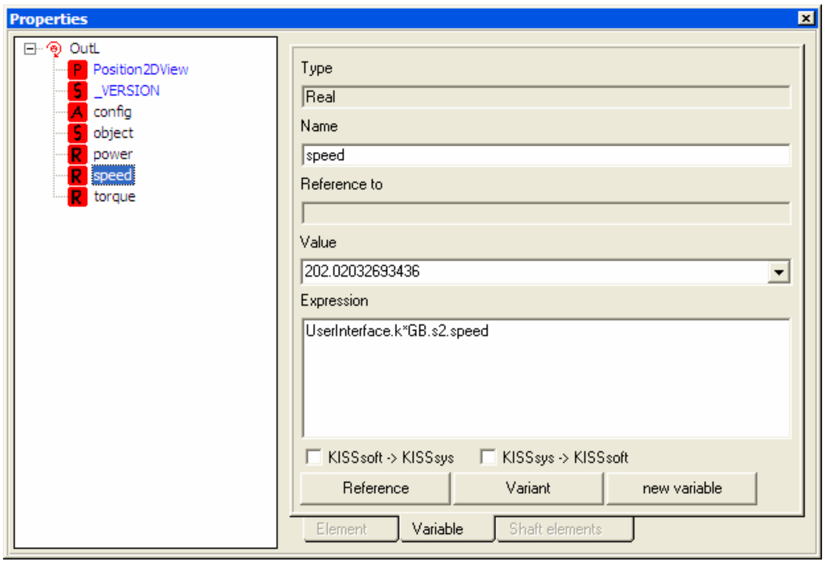

Figure 4.2-3 Make expression for the "OutL" speed

Attention: Expressions of the element variables are deleted every time you open the dialog of a "kSysSpeedOrForce".

5 Calculations

5.1 Differential bevel gears

Recommended calculation method for the bevel gears in differential arrangement is "Static calculation". This means that even if there is some speed difference inside the differential calculation is based on the static calculation with maximum possible torque. This torque needs to be defined manually for the calculations and is snot taken from the values in KISSsys.

5.2 "Simplification"

In case if you are not interested any calculations inside differential, it is recommended not to model it at all, but to use even more simplified method considering differentials as black box and to divide only torque between two outputs having equal speed.