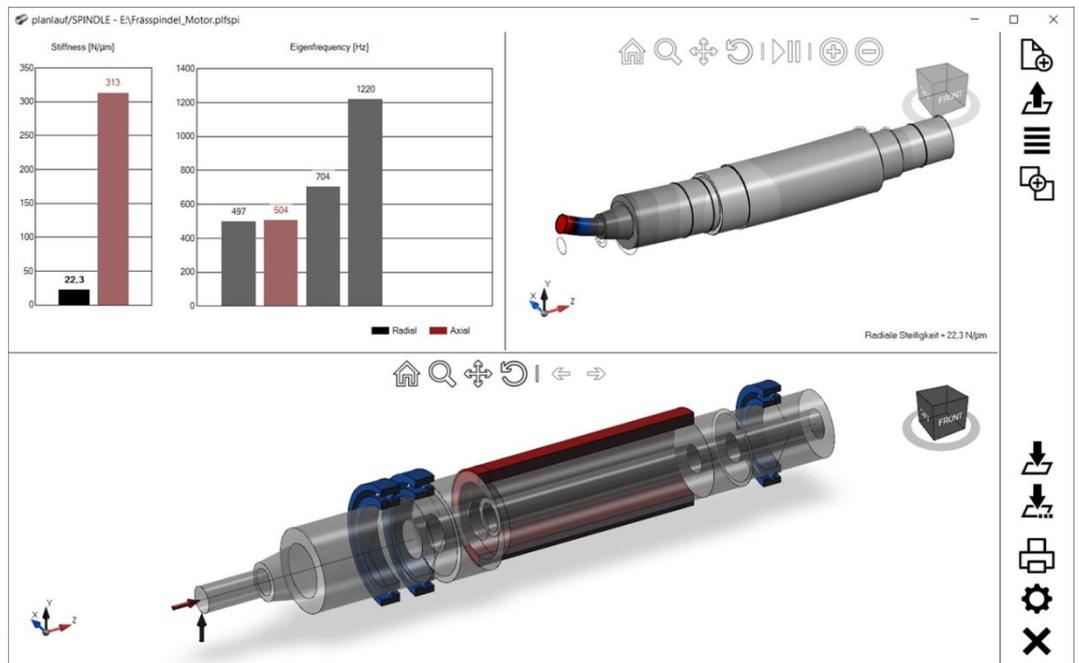




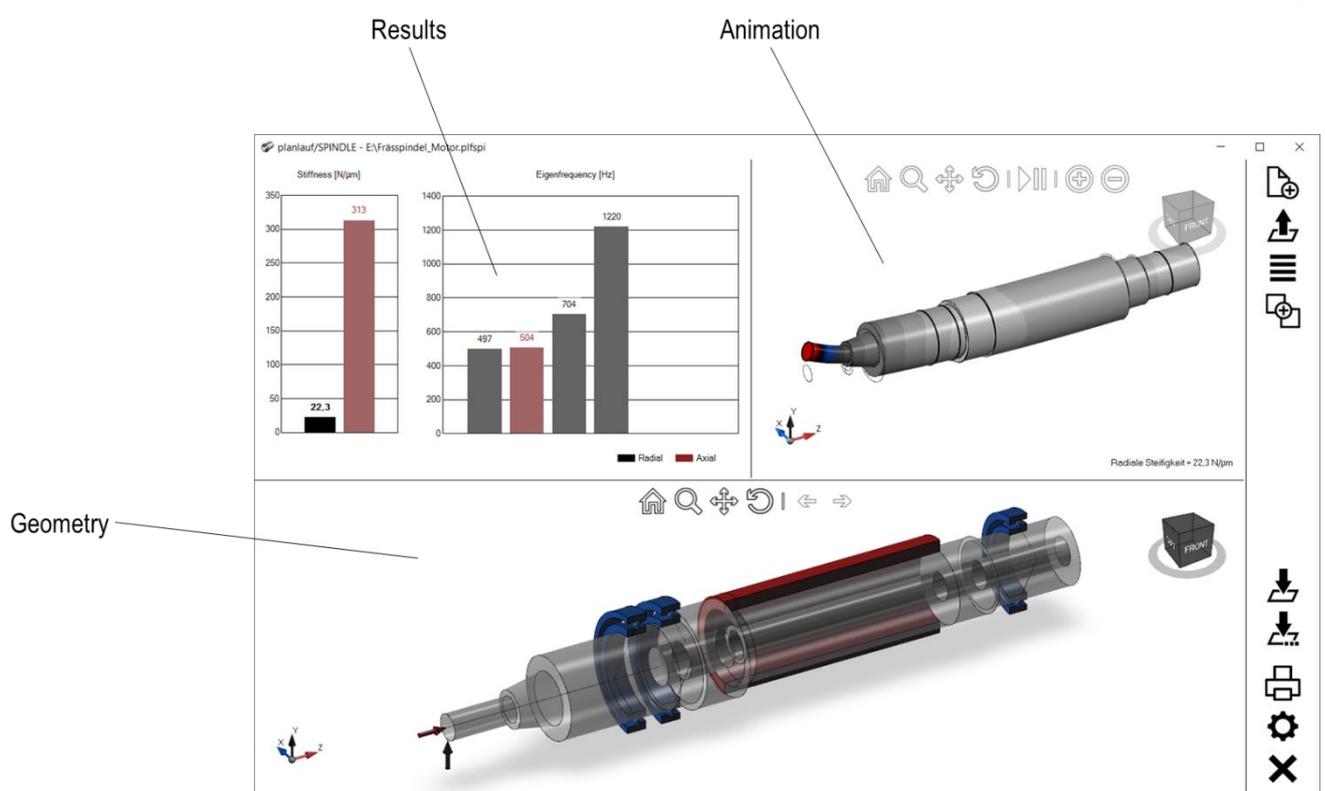
planlauf/SPINDLE simulates the static and dynamic behavior of machine tool main spindles using the Finite-Element-Analysis. The current version planlauf/SPINDLE 2023 has the following features:

- Intuitive and quick modeling with simple mouse dragging operations
- Background images (bmp, jpeg, png) as modeling templates with adjustable brightness and contrast
- Database of more than 6,000 bearings with stiffness and damping values (FAG, GMN, NSK, SKF, SNFA, IBC, TIMKEN and SLF)
- Efficient simulation of static stiffness, eigenfrequencies, mode shapes and frequency response functions with automatic refreshing after model changes
- Easy appending of models to evaluate spindle behavior with different tools
- Save locked models for distribution without the possibility to change them
- Automatic generation of reports including geometry and results
- Export geometry as a STEP file
- Export of planlauf/VIEW files to share the results
- Export of frequency response functions and displacements as a text or a CSV file



### Requirements

- OpenGL 4.0 or higher capable graphics card
- Windows 10/11 with Microsoft .NET-Framework 4.8 or higher



### Geometry

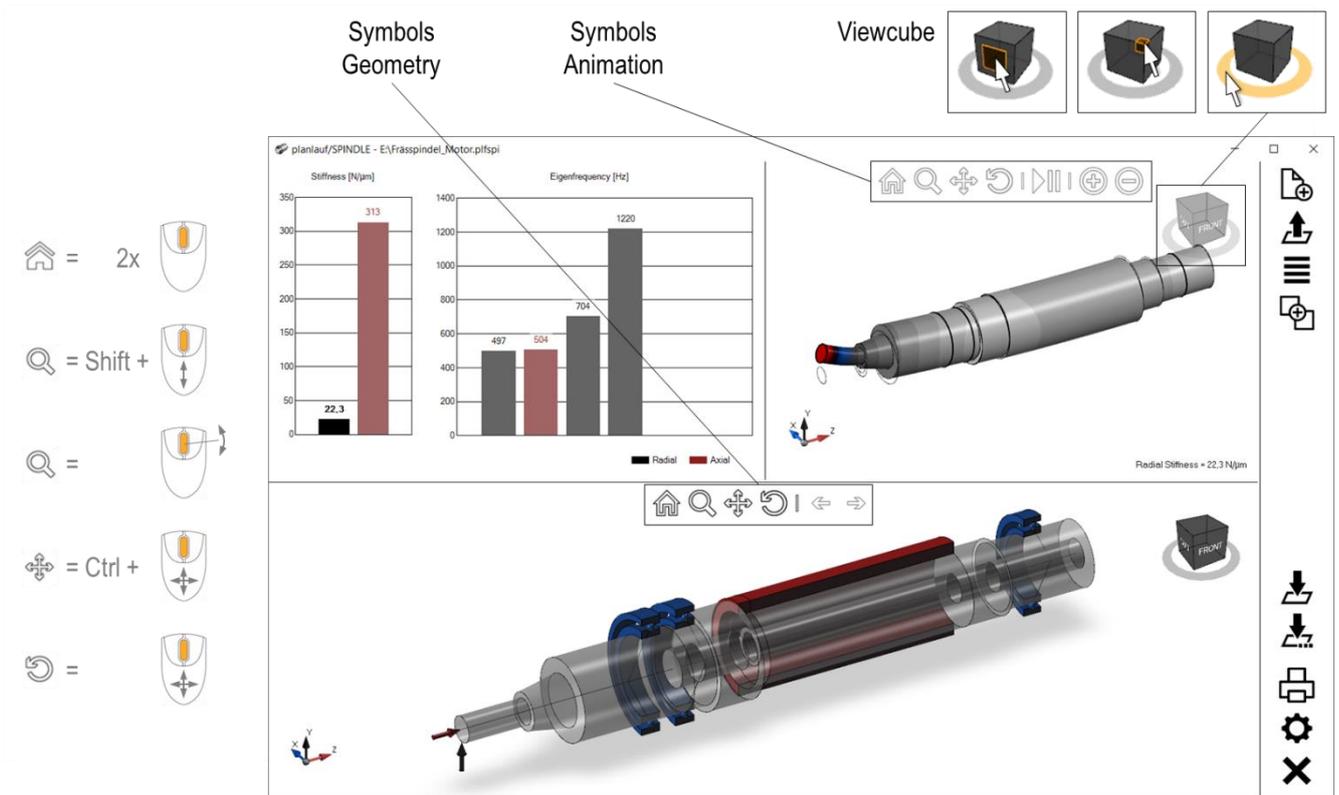
The geometry of the spindle including bearings and additional masses is defined or changed in this area with simple mouse dragging operations.

### Results

The spindle's static and dynamic behavior is shown in this area. Change the display between "Stiffness / Eigenfrequency" and "Frequency Response Functions" by selecting the appropriate option in the context menu.

### Animation

Static displacements and mode shapes are displayed in this area.



**Symbols Geometry**

Use **Standard View** to reset the camera to the predefined view. If **Zoom** , **Pan** or **Rotate** is active and the left mouse button is pressed, the view can be changed by moving the mouse. **Undo model changes** by or by pressing CTRL+Z.

**Symbols Animation**

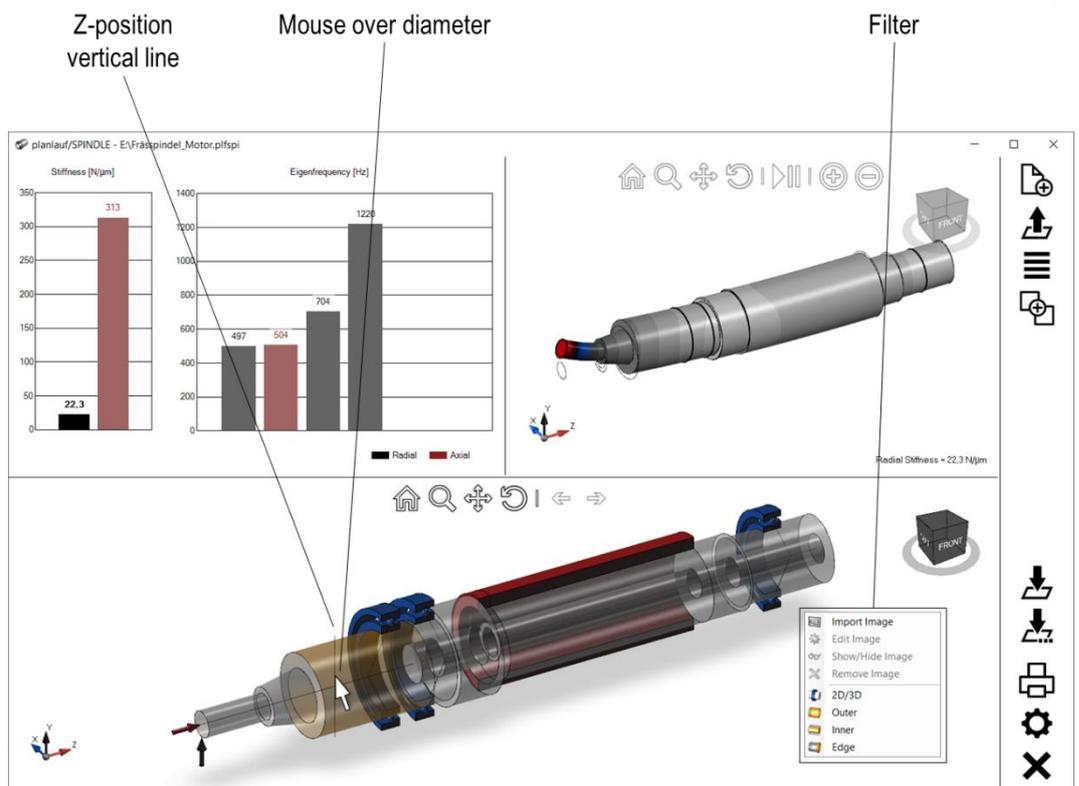
3D control works in the same way as in the geometry area. **Start or stop** the animation with . The **deformation factor** controls the amplification of the calculated deformation.

**Viewcube**

Use the viewcube of the geometry and animation area to set common standard views. The views are highlighted if the mouse hovers over them. You can select faces, edges and corners. When the mouse is over the ring and the left mouse button is pressed, the model can be rotated around the vertical axis.

**Remark:** planlauf/SPINDLE supports **3Dconnexion** devices as well as the usual CAD 3D control with the **middle mouse button** (rotate, additionally press SHIFT to zoom or CTRL to pan).

On a **touchscreen**, tap on an element in the geometry area to select it and perform the drag operation. You can display a context menu by pressing your finger on the display for a moment. If a touchscreen is used, the 2D mode is recommended to manipulate the elements more easily.



Depending on the mouse location, the possible features for selection or modification are highlighted. The following features can be highlighted:

- Outer diameters of segments
- Inner diameters of segments
- Edges at the end of segments
- Forces
- Bearings
- Springs
- Additional masses

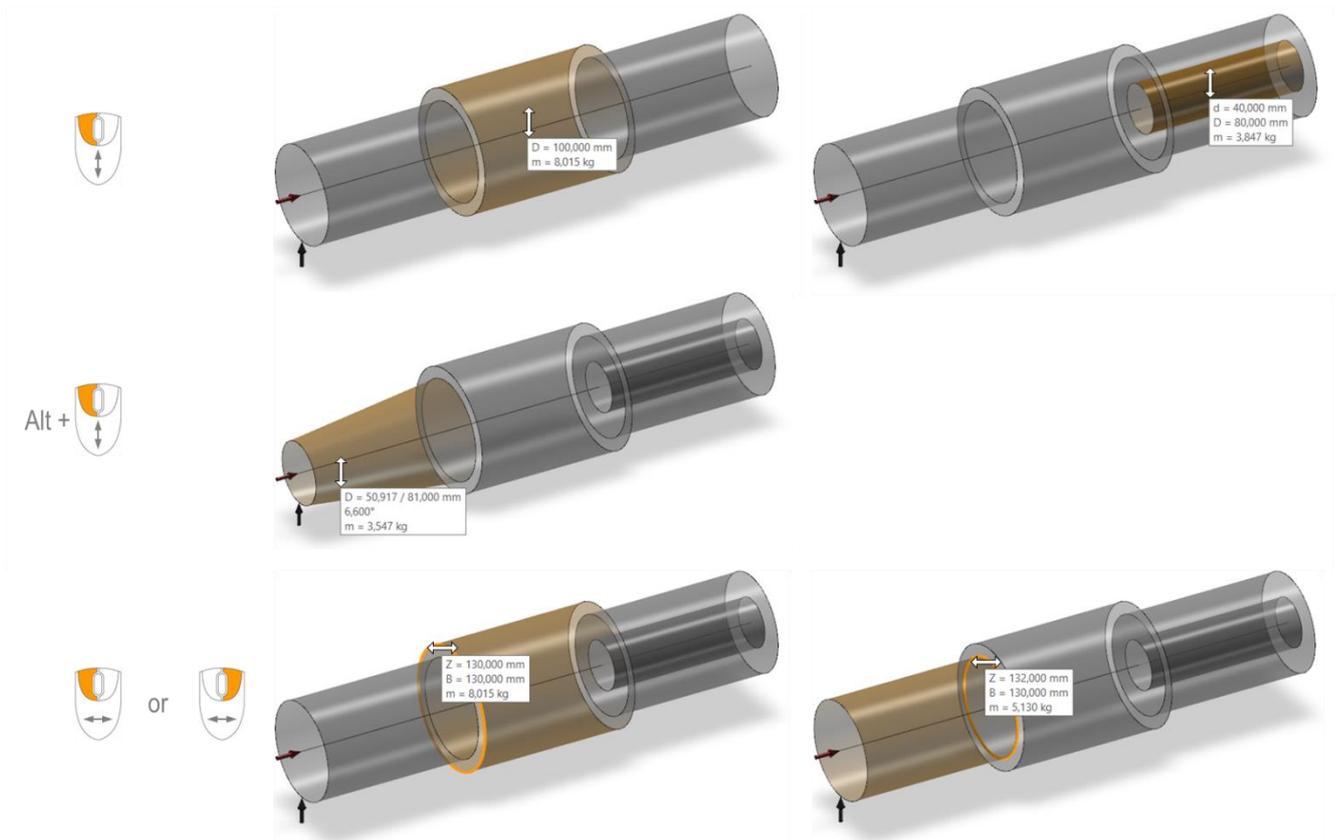
Selection of **multiple outer or inner diameters** is possible if the **CTRL** key is pressed and the diameter is clicked. The first selected feature defines the selection filter to ensure that the selection contains only features that can be modified simultaneously. Clear the selection by clicking within the geometry area at a location outside the spindle. You can also press the **ESC** key to clear the selection.

The current Z-position is shown with a **vertical line** in the geometry area. This line can be hidden in the settings.

The context menu of the geometry area contains the **selection filter** for diameters or edges and the button to switch between **2D and 3D mode**.

## Geometry

## Geometry Changes by Dragging



### Outer and inner diameters

Press the **left mouse button** over a highlighted diameter or a selection of diameters and move the mouse up (down) to increase (decrease) the size. The current value and the mass of the segment(s) are shown in the info box.

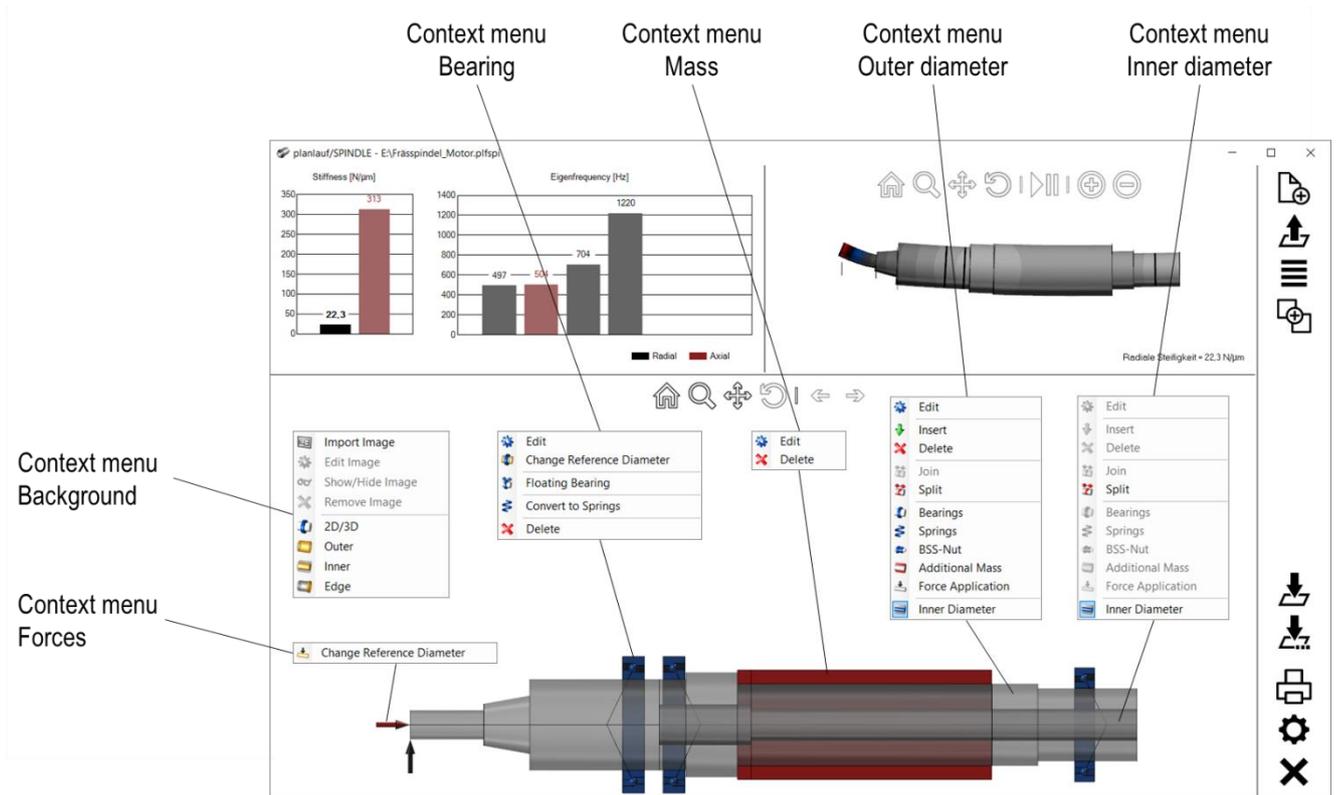
### Conical outer diameter

The cone of the highlighted outer diameter can be modified with the **left mouse button** and the **ALT key**. Depending on the mouse location, either the left or the right diameter is modified. The other diameter will remain unchanged and the angle is shown in the info box.

### Edges

Edges are highlighted together with their segment. Use the **left mouse button** over a highlighted edge to move it left or right and change the length of the highlighted segment. Use the **right mouse button** to keep the position of the neighboring segments and change the segment length in favor or at the expense of the neighboring segment. The info box shows the current Z-position of the edge, the length of the highlighted segment and its mass. Press the **SHIFT key** over an edge and the left mouse button to move the whole spindle.

**Remark:** **CTRL+A** or **CTRL+I** adds all outer or inner diameters to the selection.



All geometry commands are available through context menus. Which context menu is shown depends on the location of the mouse when pressing the right mouse button.

### Context menu “Background”

Import an image (bmp, jpeg, png) which is placed on the YZ plane of the geometry area.

### Context menu “Outer diameter”

This context menu is shown if the mouse is located on an outer diameter and contains all commands that are needed to define or modify the model’s geometry.

### Context menu “Inner diameter”

Each segment is defined by its outer diameter. Additionally an inner diameter can be used. The context menu enables activating or deactivating the inner diameter.

### Context menu “Mass”

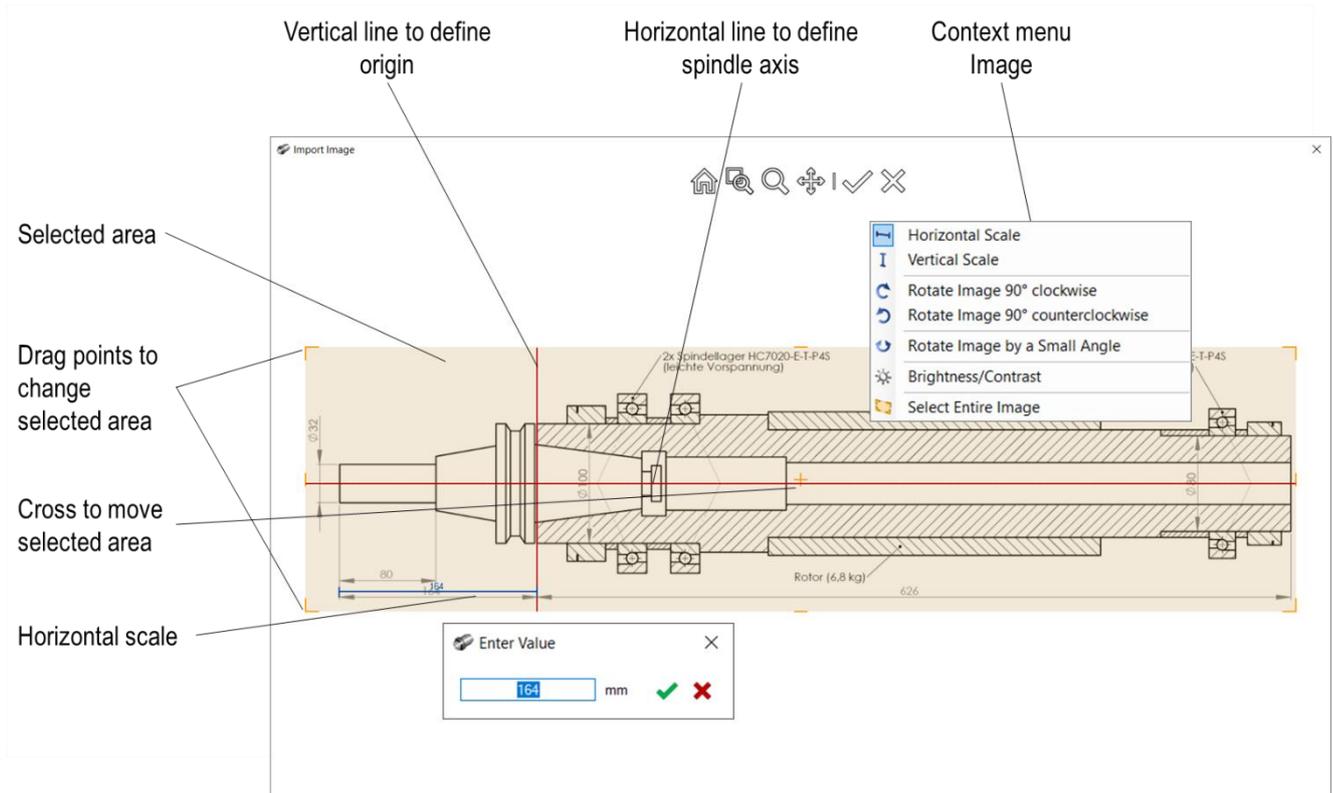
Additional masses contribute to the mass and not necessarily to the stiffness of the model. Modify or delete the mass with this context menu.

### Context menu “Bearings”

Modify or delete a bearing or a set of bearings with the commands in this context menu.

### Context menu “Forces”

The forces are associated to one outer diameter (= reference diameter) which can be changed in this context menu.



Choose the image file (bmp, jpeg, png) by clicking on “Import Image” within the background context menu in the geometry area. The image is then displayed in the image window. Pan and zoom the image with the same commands as the ones in the geometry or animation area. Accept the image with the check mark after all settings are made.

**Vertical and horizontal lines**

Press the left mouse button over the vertical red line to move it and define the origin. The horizontal line defines the spindle axis.

**Selected area**

The selected area is highlighted in orange and can be modified with the drag points in the corners, on the edges and at the center.

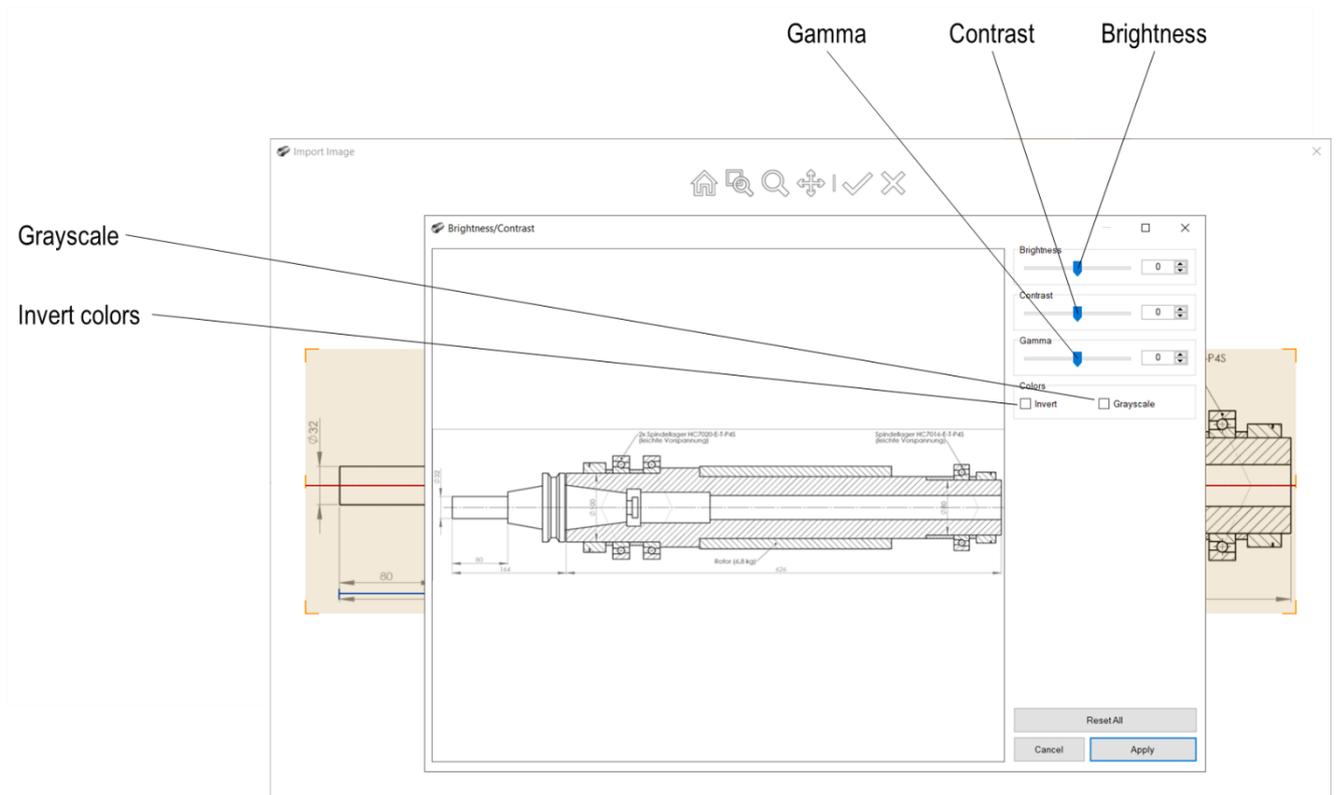
**Horizontal and vertical scale**

The two blue scales are used to define the ratio between the image size in pixels and the actual size in millimeters. At least one scale has to be used, the second can be deactivated. The length of the scales and their location can be modified by dragging the end points or the line. Change the value by clicking on it.

**Context menu “Image”**

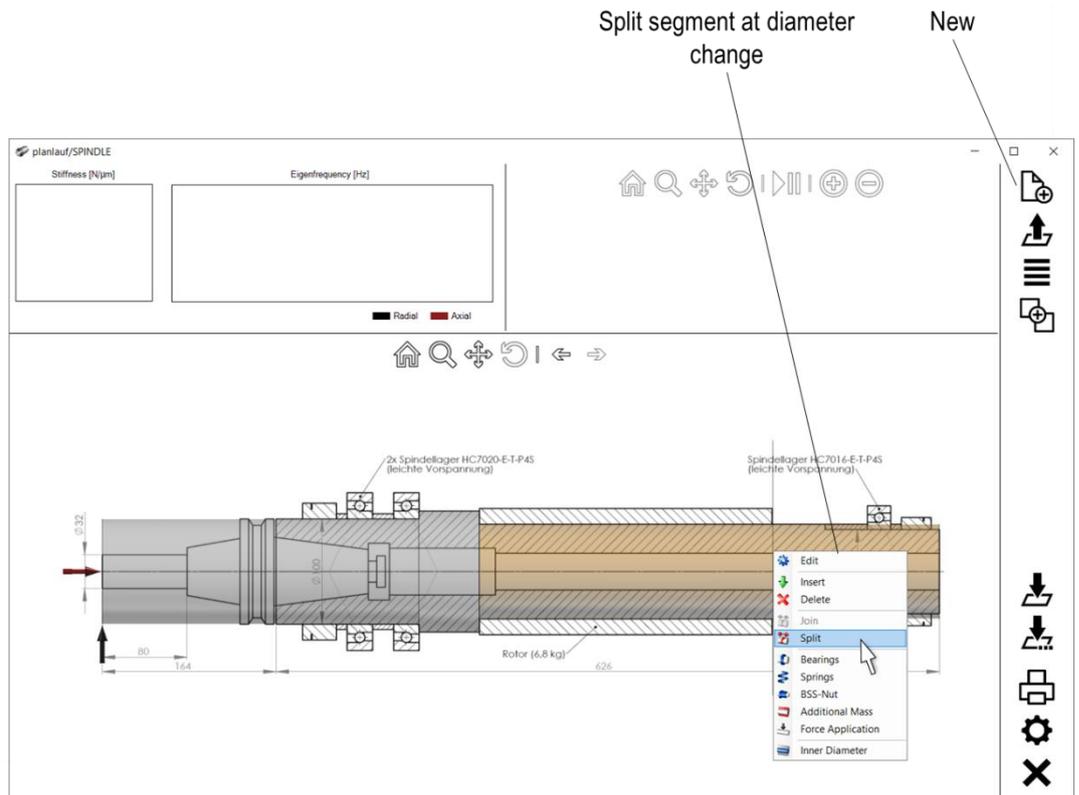
In this context menu, the scales can be activated or deactivated, the image can be rotated by 90° or any other angle, the settings for brightness/contrast can be shown and the entire image can be selected.

**Remark:** All geometry modifications are based on left edges so it is recommended to make sure the tool and the forces are also on the left side.



This window is shown after the command “Brightness/Contrast” in the context menu “Image” is called. The preview window immediately shows the image with the selected settings for **brightness, contrast and gamma**. **Inverting the colors** might be useful for the import of screenshots from AutoCAD with a black background. Additionally, the image can be converted to **grayscale**.

**Remark:** Calculating the preview image takes some time and is faster if the preview window is small.

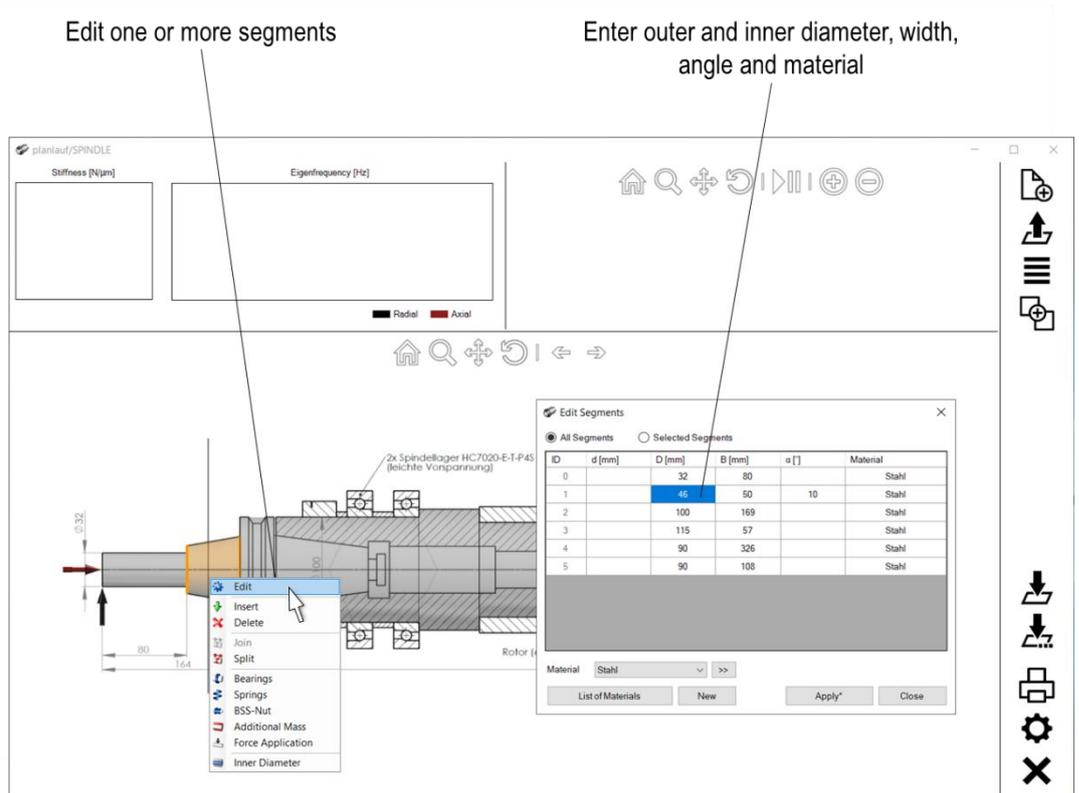


The geometry of a spindle can be defined by the following steps:

- **New:** the model consists of one segment and the forces
- Import a background image
- Drag the left (right) edge of the segment to the left (right) end of the spindle including the tool
- Split the segments at all locations where the outer diameter changes (context menu “Outer diameter” or **SPACE key**)
- Drag the outer diameters to their correct value
- Move the edges of the segments if necessary

There are some additional commands in the context menu “Outer diameter”:

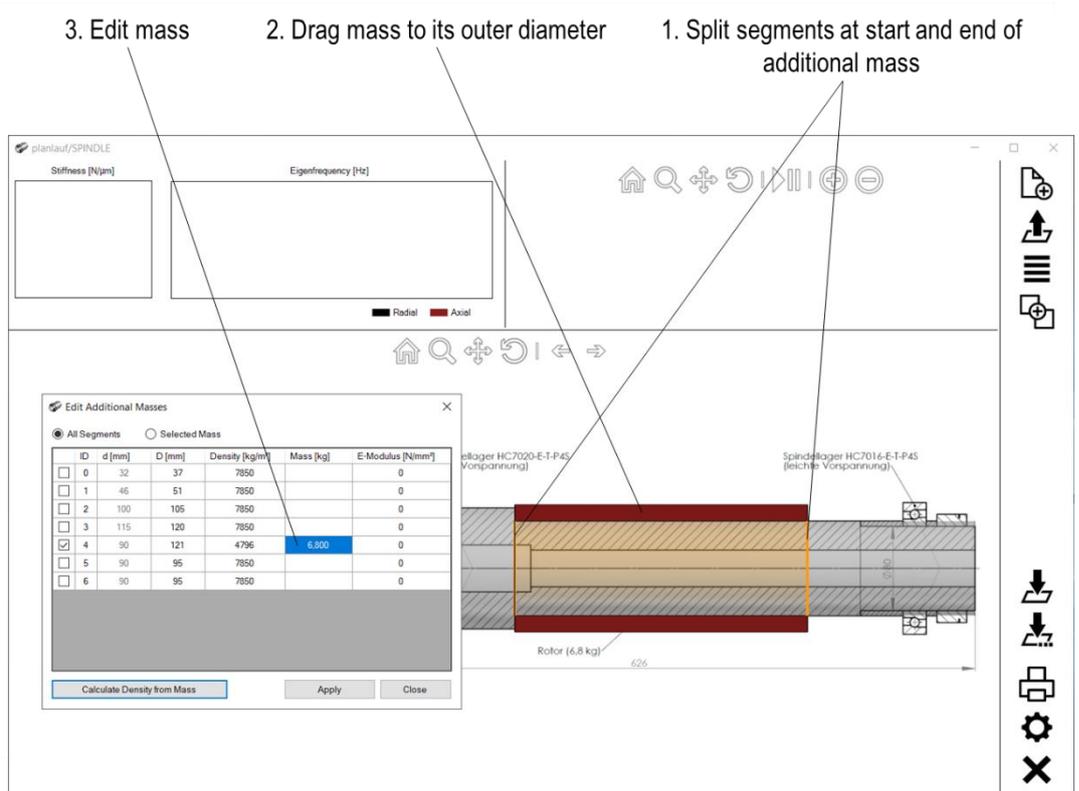
- **Insert:** Depending on the mouse location, a segment with identical properties will be added to the left or to the right of the highlighted segment.
- **Delete:** The highlighted segment or the selection will be deleted. This command is available with the **DELETE key** as well.
- **Join:** Neighboring segments in a selection are joined into one continuous segment with the properties of the first segment in the selection.



Apart from the dragging operations, the geometry can also be modified in the segment list. **Double-clicking** on a segment/selection or the “Edit” command in the context menu “Outer diameter” will show the list.

Selected rows in the list are also highlighted in the geometry area. Select multiple cells and press the right mouse button to assign a value to all of them at once.

Main spindles are mostly made from steel. Other **materials**, e.g., carbide for the tool can be assigned in the segment list. Common materials are pre-defined, others can be added with the “New” command. Assign a material by marking the segments in the table and pressing the “>>” button or choosing a material from the dropdown list.



Define additional masses with the following steps:

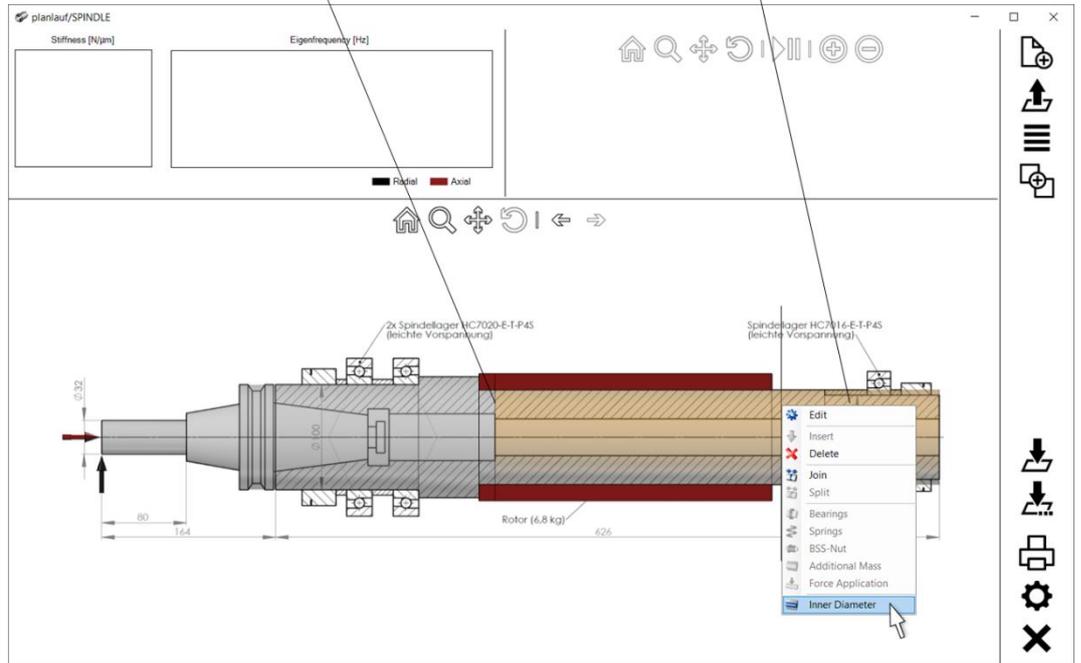
- Split the segments at the start and the end of the mass
- Drag the outer diameter of the mass to its value
- Edit the mass (**double-click** or context menu “Mass”) and enter the appropriate value

Choose if you want to display **all** or **only the selected segments** at the top of the window. Check the marks in the first column to assign masses to the segments. The geometry of the mass is defined by the length and the outer diameter of its segment and its own outer diameter. planlauf/SPINDLE uses the density and the geometry to calculate the mass. Increasing the outer diameter results in an increasing mass. Calculate a density value for a given mass by clicking on the “Calculate Density from Mass” button.

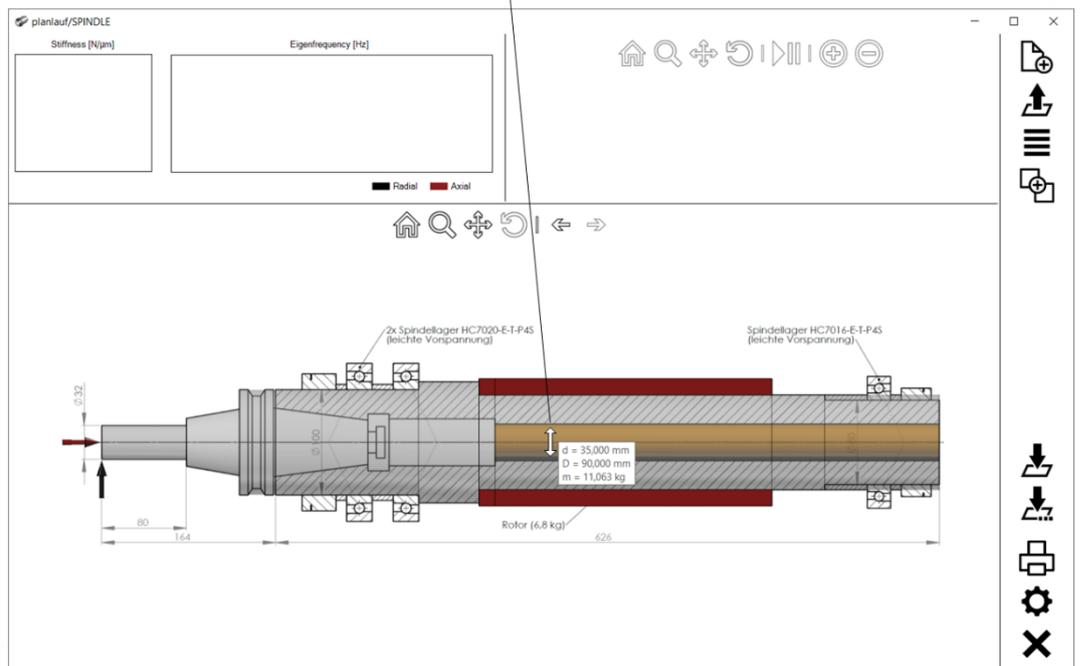
Entering a Young’s modulus into to last column allows for a **stiffness contribution** of the mass. A rotor might be represented with a modulus of 100,000 N/mm<sup>2</sup> (steel: 210,000 N/mm<sup>2</sup>).

1. Split segments at all changes of inner diameter

2. Select all segments with the same inner diameter



3. Drag inner diameter to its value

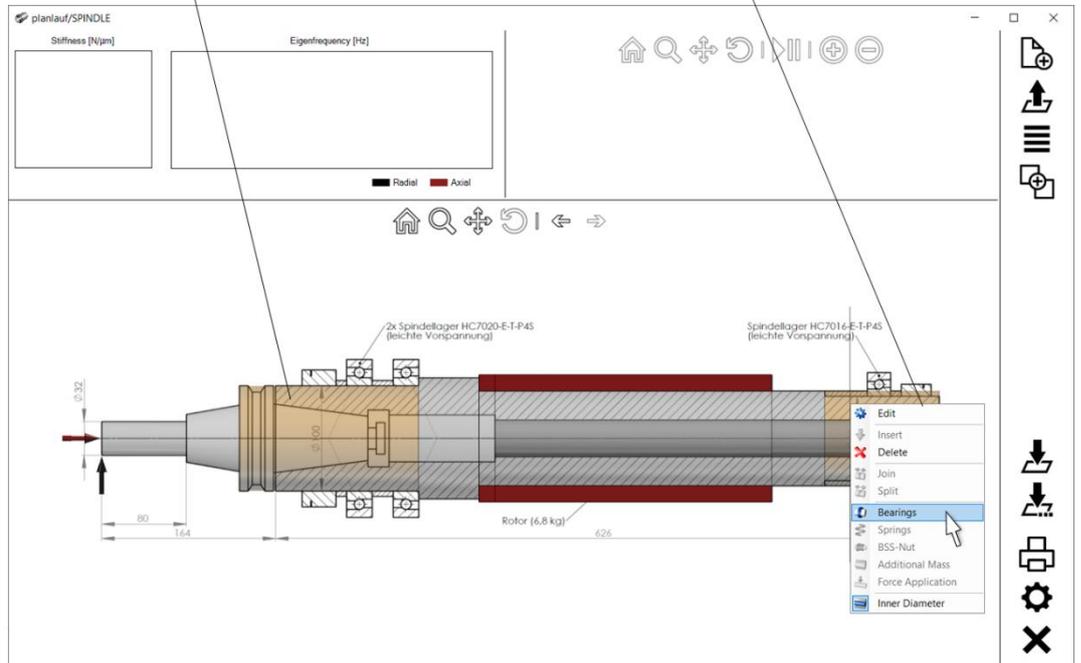


Define inner diameters with the following steps:

- Split the segments where the inner diameter changes
- Select all outer diameters with the same inner diameter
- Activate the inner diameter in the context menu “Outer diameter” and drag the now selected inner diameters to their value

1. Click on front bearing segment and press CTRL

2. RMB to get context menu on rear bearing segment, choose 'Bearings'

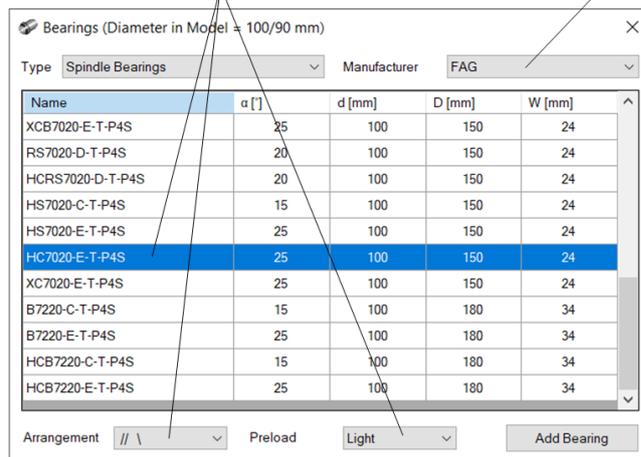


Spindle bearings are usually used in sets, so the front and the rear seat are not on the same segment. In addition, the diameter of the front and rear seat can be different. Define a set of spindle bearings on two different segments (one segment is also possible) with the following steps:

- Click on the front and then the rear bearing segment while pressing the CTRL key
- Choose "Bearings" in the context menu "Outer diameter"

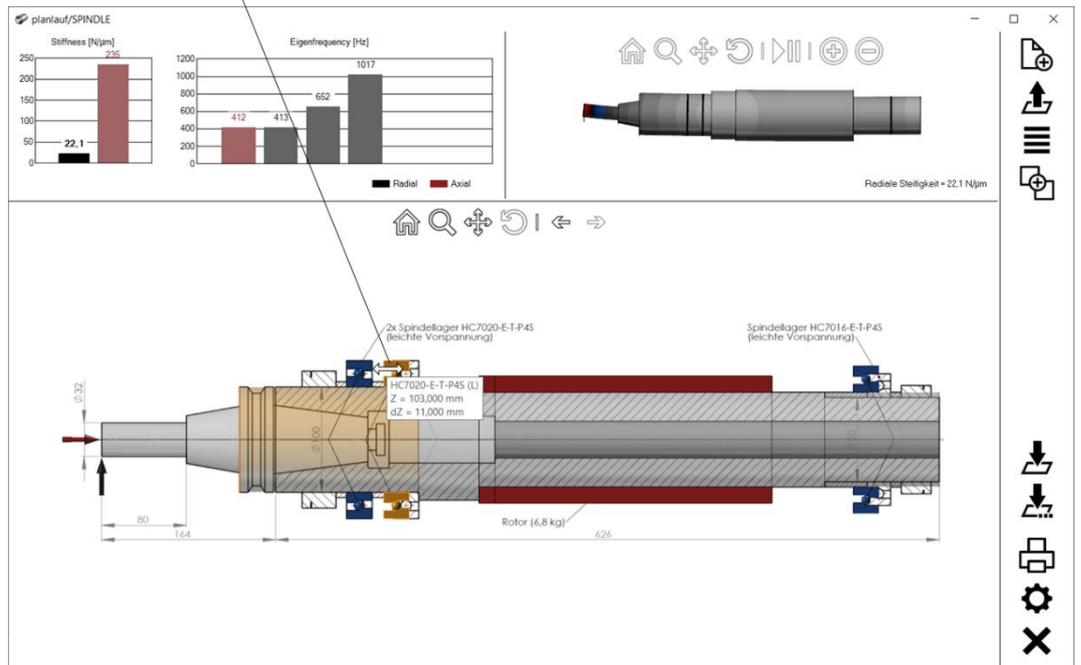
4. Choose bearing, arrangement and preload

3. Choose bearing manufacturer



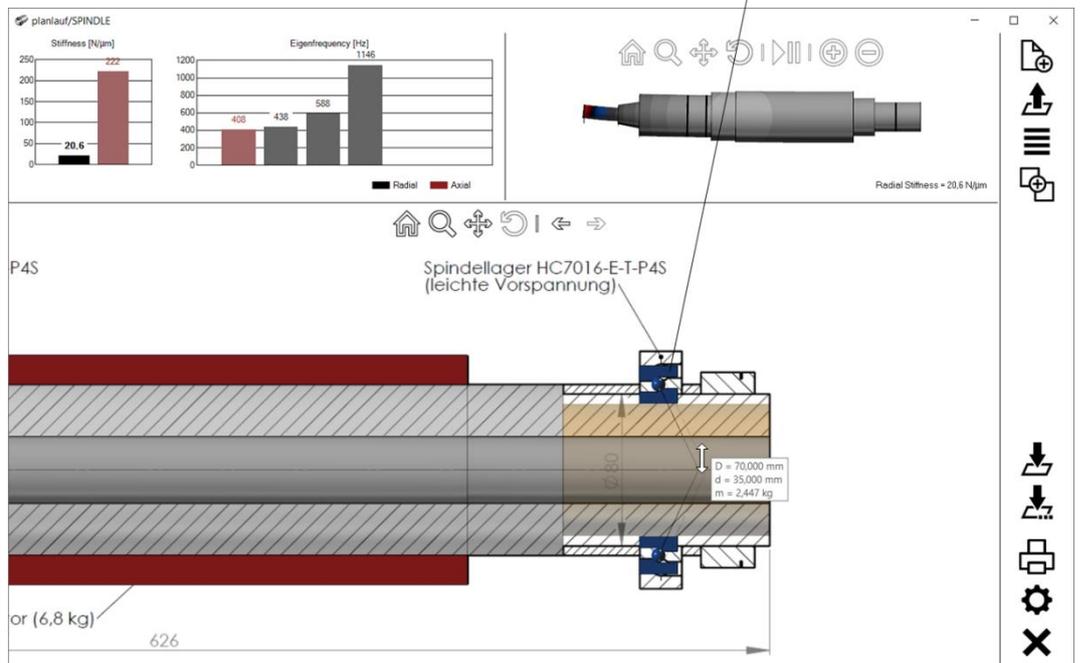
- Choose "Spindle Bearings" and the manufacturer in the dropdown lists
- Choose the bearing type, the arrangement (e.g. // \ or // \\\) and the preload

### 5. Drag bearing to its location

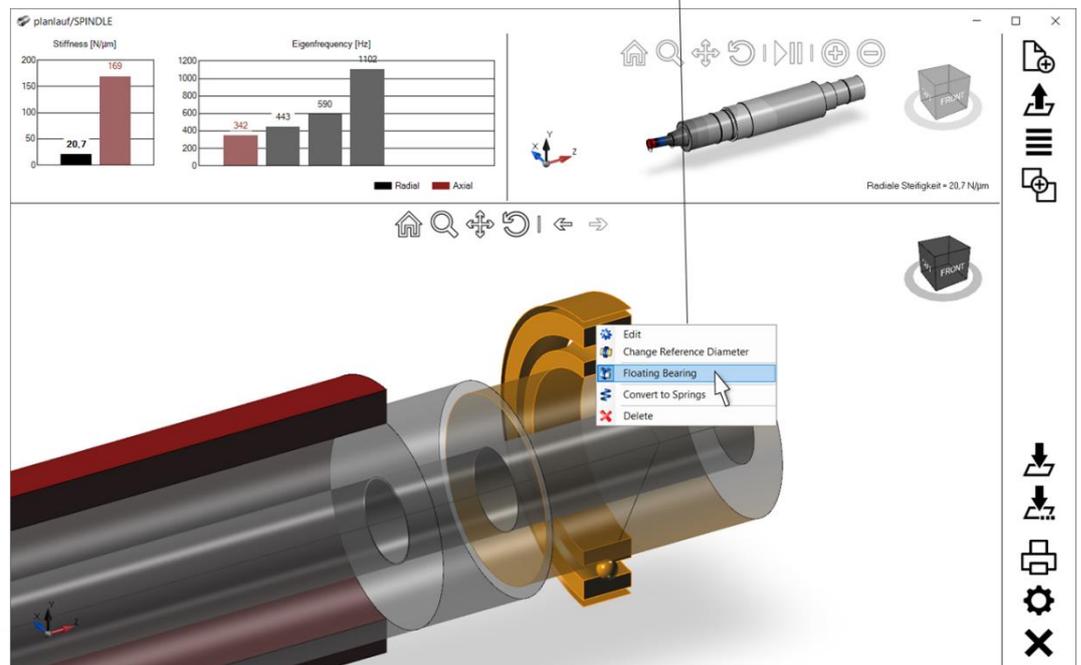


- Drag the bearings to their positions (the position of the first bearing is defined relative to the left edge of the segment, the other bearings are positioned relative to their left neighbor)
- The bearing size is automatically adjusted to fit the outer diameter of the segment.

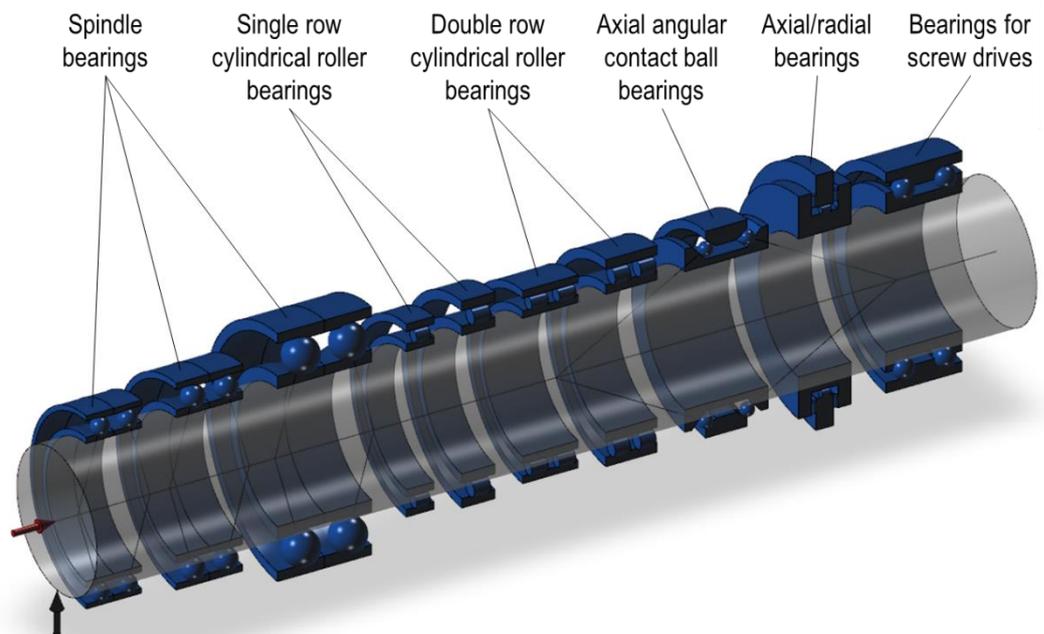
Bearing size is automatically adjusted to outer diameter



## Definition of a floating bearing

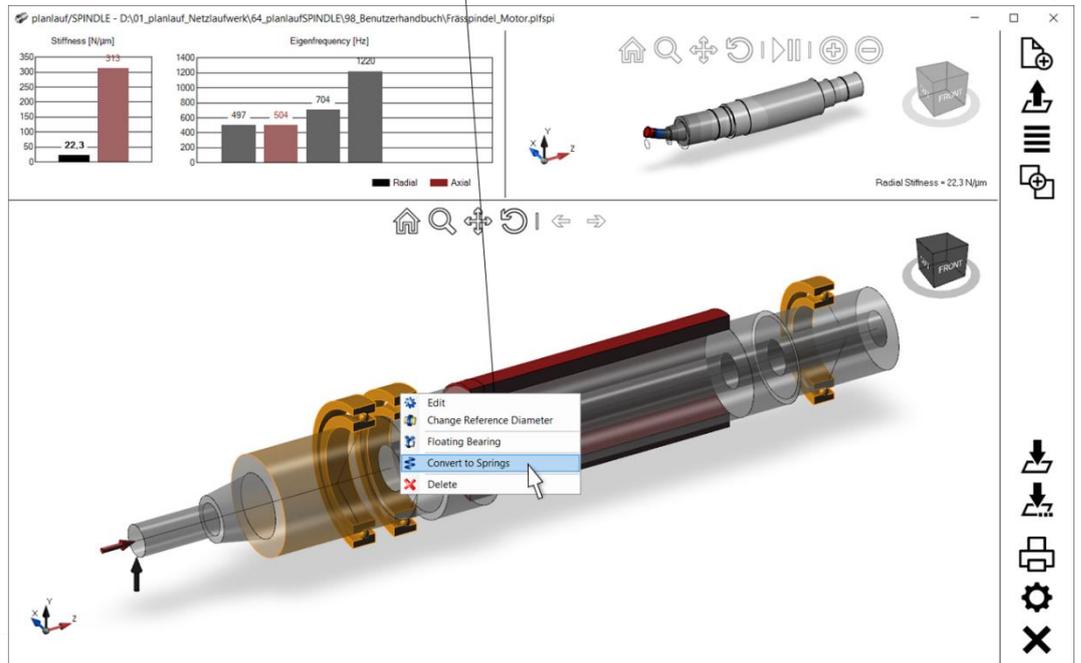


Some bearings are used as floating bearings and don't contribute to the axial stiffness of the bearing set. Select the "Floating Bearing" option in the context menu "Bearings" to set the axial stiffness to zero. Floating bearings are marked with an additional ring.



The bearing database consists of spindle bearings from the most important manufacturers (FAG, GMN, NSK, SKF, SNFA, IBC, TIMKEN, SLF), cylindrical roller bearings, angular contact ball bearings, axial/radial bearings and bearings for screw drives. There are more than 6,000 bearings with their stiffness and damping values included.

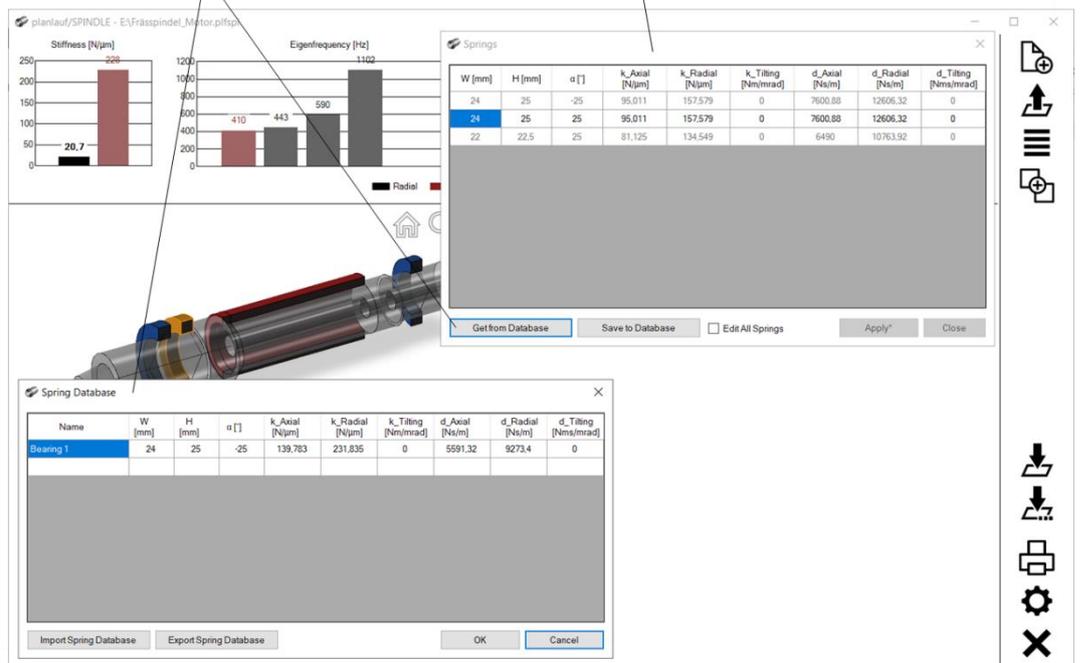
Convert bearings to springs



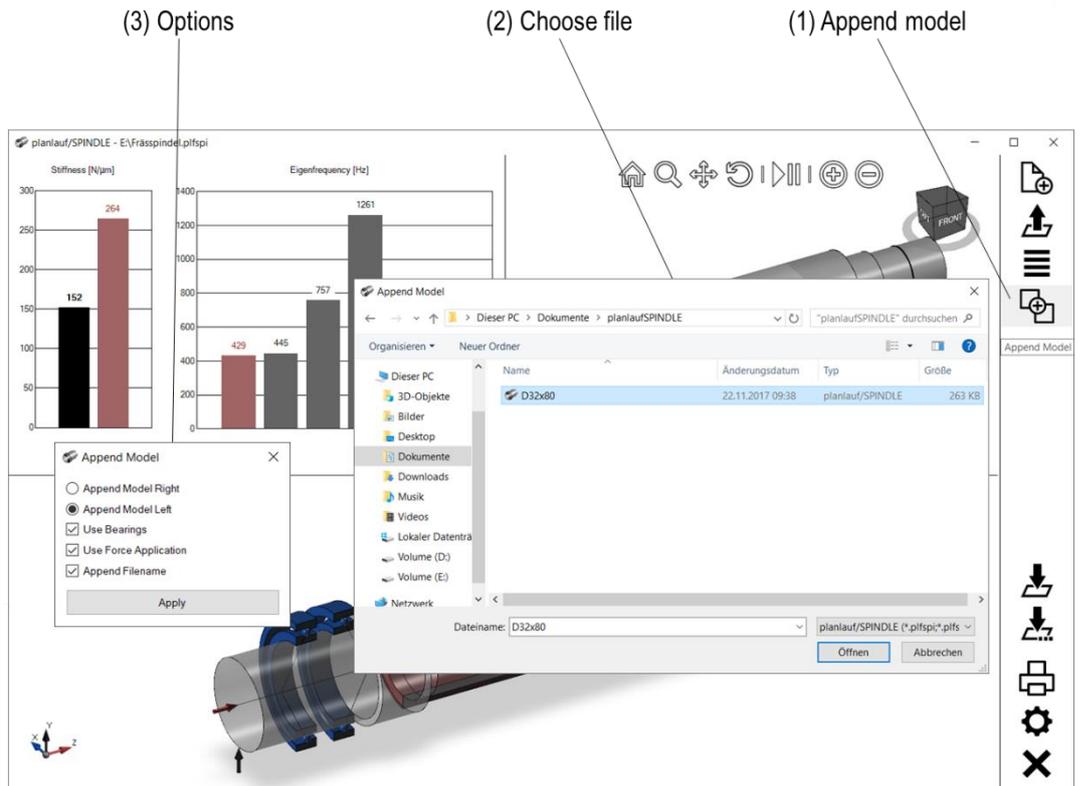
Springs with translational and rotational stiffness and damping values can also be defined (context menu “Outer diameter” > “Springs”). Additionally, bearings or bearing sets can be converted to springs (context menu “Bearings” > “Convert to Springs”) or be taken from a database. Move the springs with the same mouse dragging operations as the bearings.

Spring Database

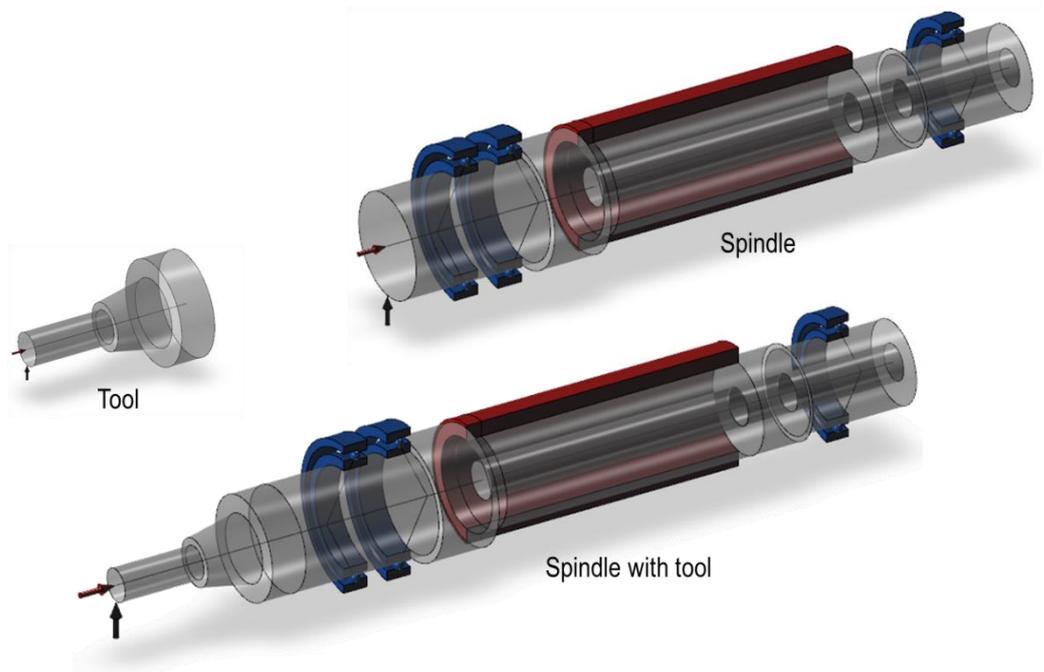
Geometry, angle, stiffness and damping values



**Remark:** The **angle** (negative: to the left, positive: to the right) considers the stabilizing effect of X arranged bearings.

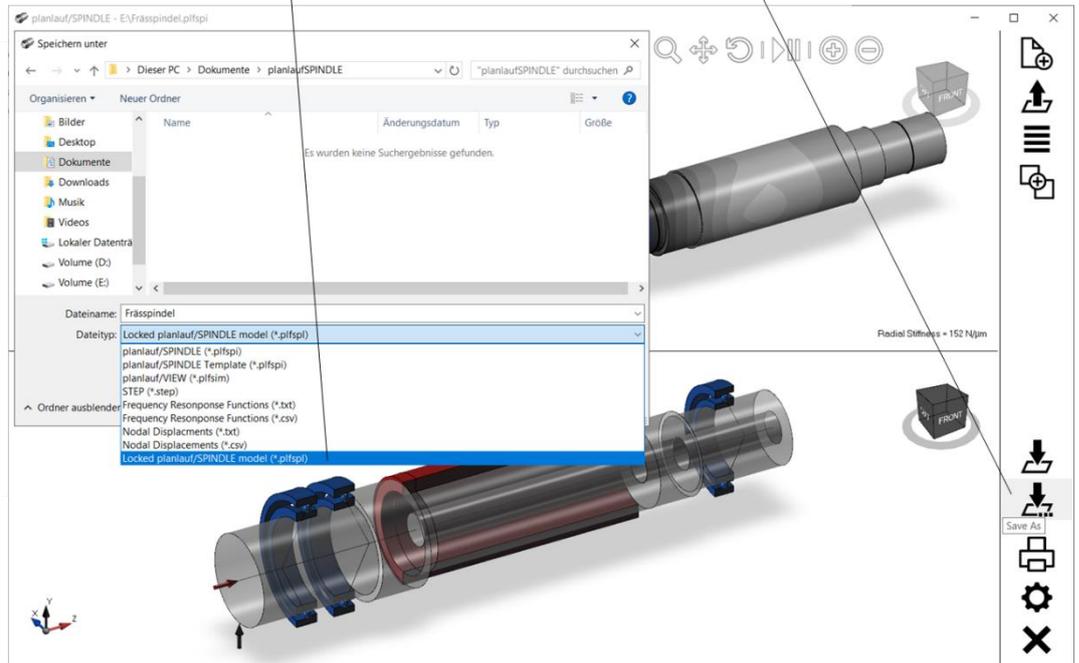


Existing models can be appended to the current one with the “Append Model” command. Choose the file and select the option to append the model to the **left or right**. Select the option to import the bearings if appropriate. Appending tools to spindles usually requires to use the forces’ location at the TCP. You can also combine the filename of the current model and the appended one.



(2) Locked planlauf/SPINDLE model

(1) Save As

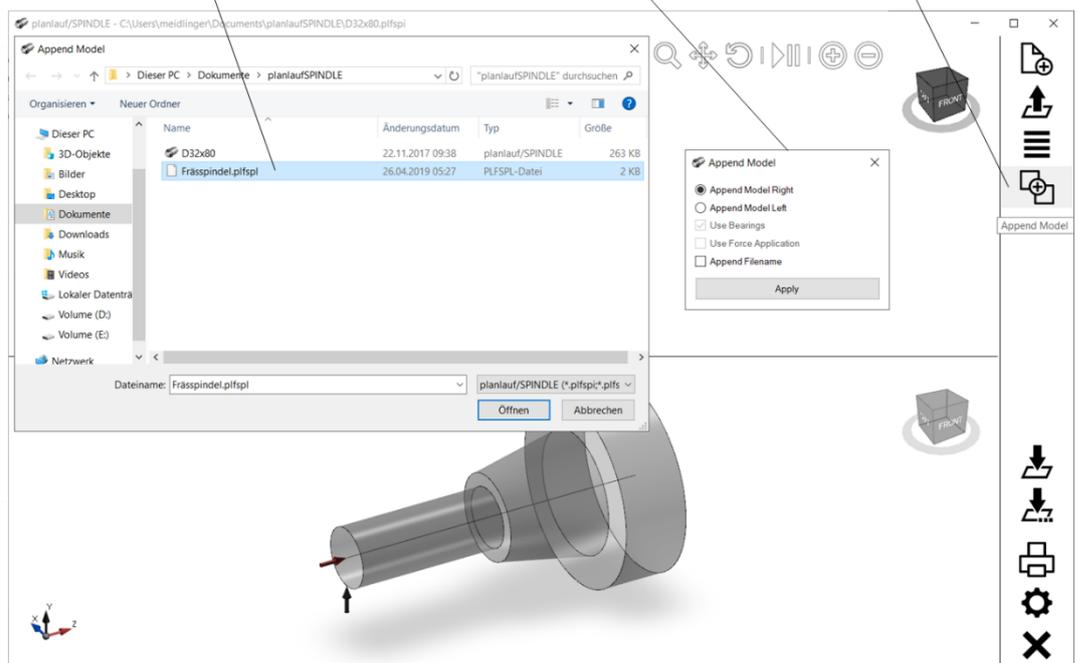


planlauf/SPINDLE models can be saved in a locked state where no changes are possible anymore. This format is useful if a spindle manufacturer wants to provide a simulation model to one of its customers. The customer can then calculate the eigenfrequencies for different tools. Click on the "Save As" button and choose the file type "Locked planlauf/SPINDLE model" to save the file with the extension \*.plfspl.

(2) Locked planlauf/SPINDLE model

(3) Append Model Right

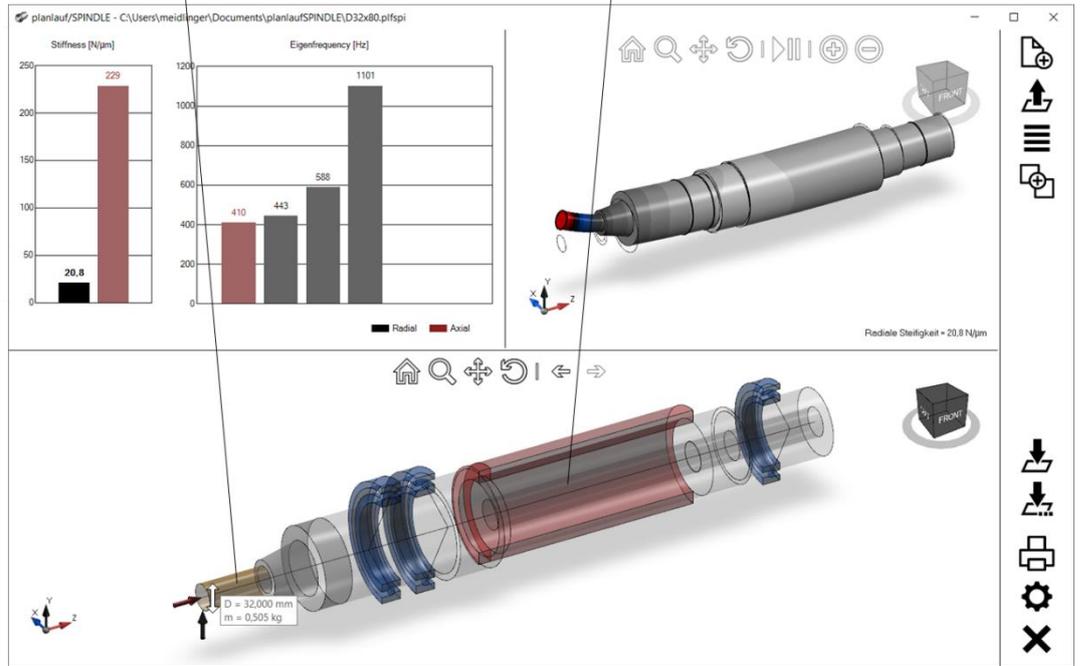
(1) Append Model



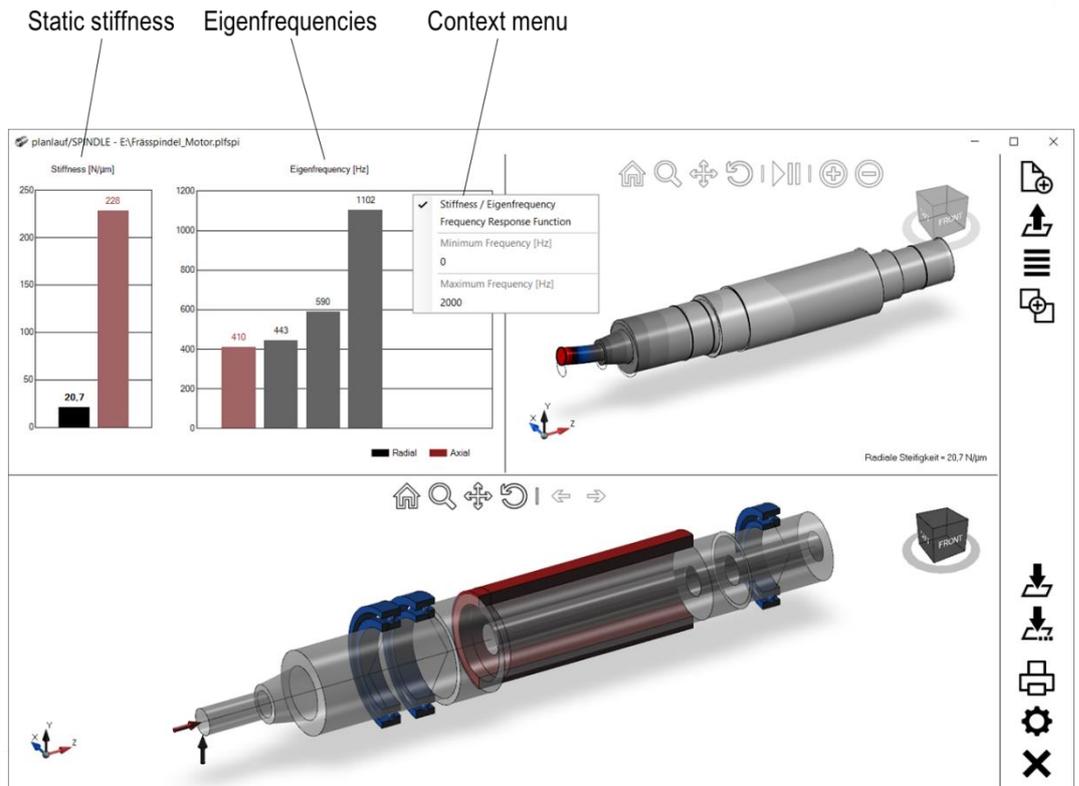
Open a tool, click on the button "Append Model" and choose the locked spindle to create the combined model.

### Editable elements

### Locked elements

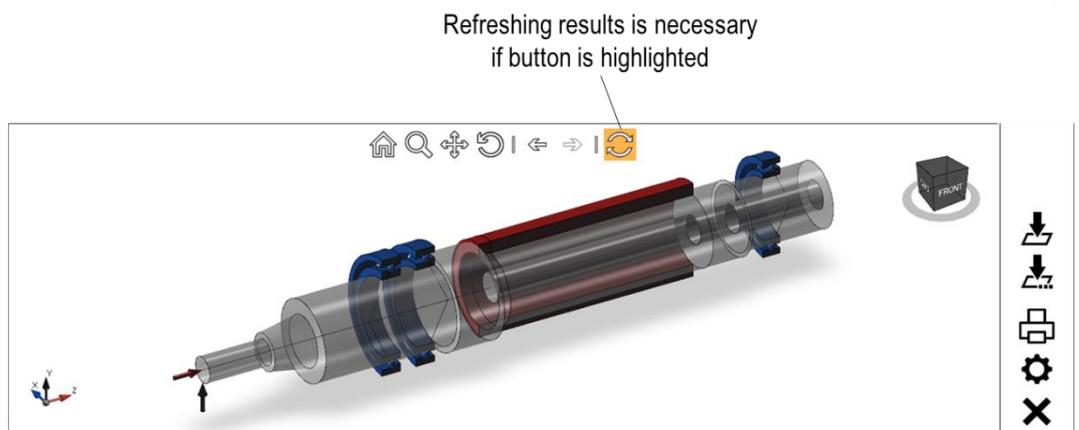


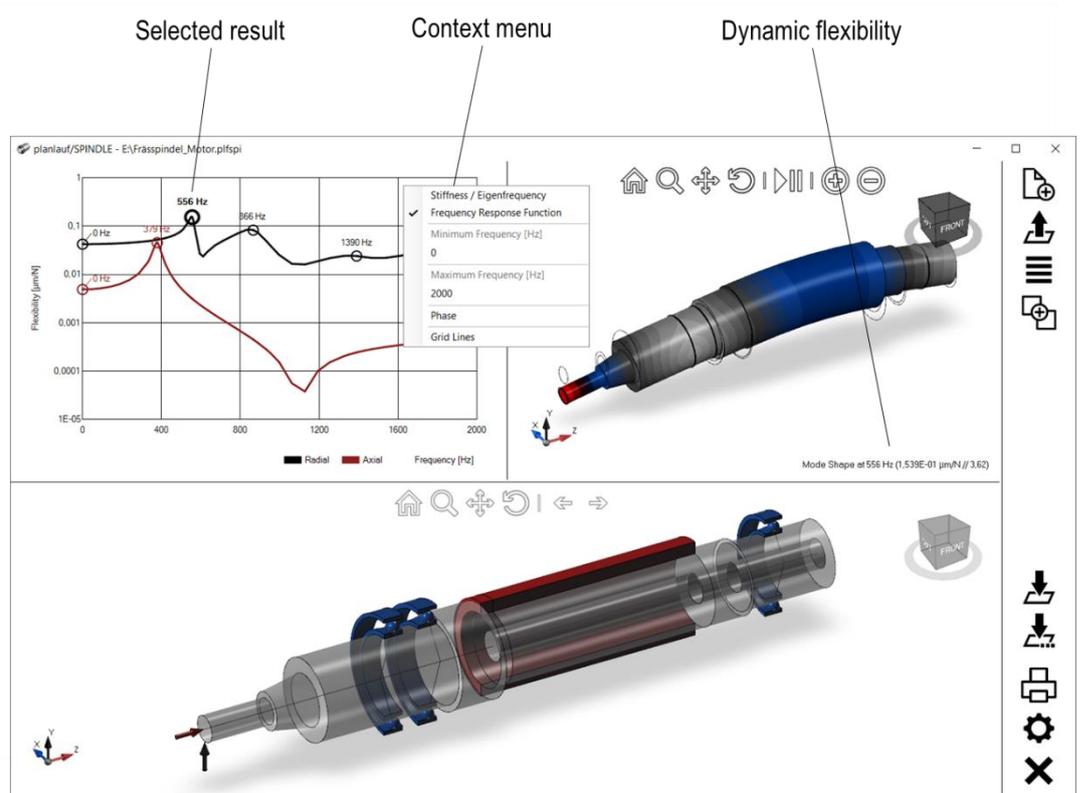
The combined model contains the editable elements of the tool and the locked elements of the spindle. Locked elements are shown more transparently and are also not accessible through the context menus or the tables.



The results are shown in the top half of the window. If the option “Stiffness / Eigenfrequency” is chosen the results are displayed as bar diagrams on the left. Click on a bar to visualize the deformation or the mode shape on the right. **Black (red)** bars represent radial (axial) deformations or mode shapes. There are six eigenfrequencies that can be shown. If needed the frequency range can be changed in the context menu of the diagram.

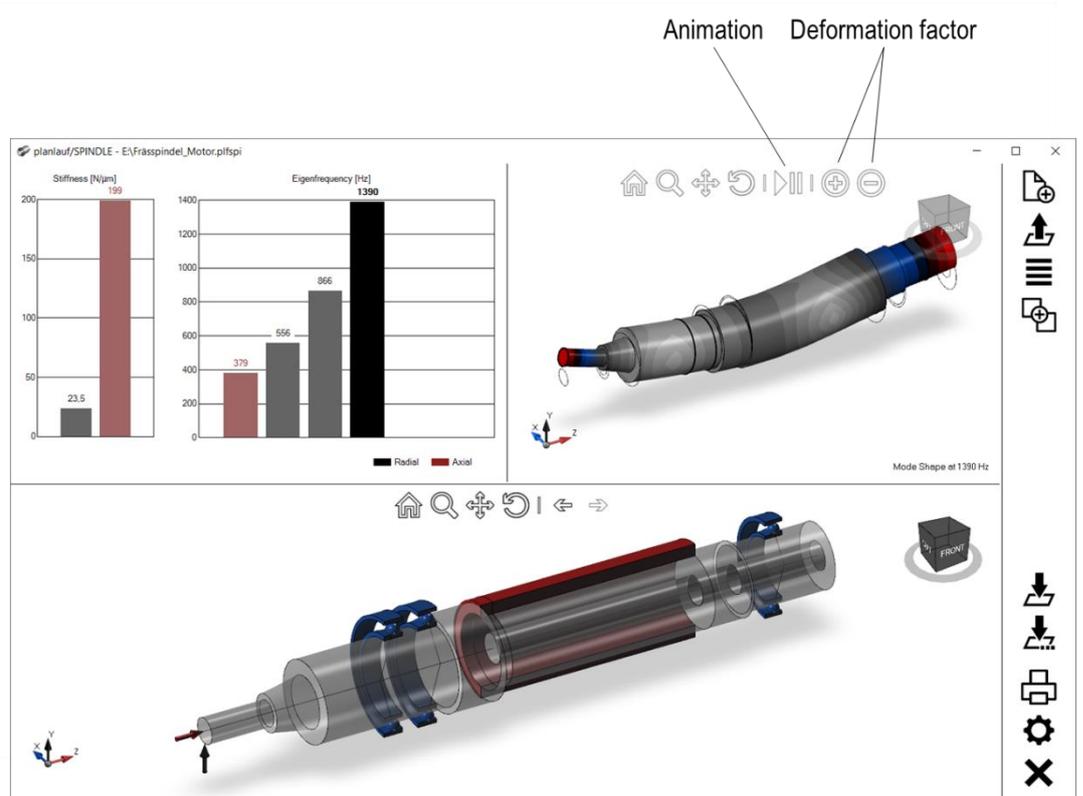
**Remark:** By default the results are updated as soon as the geometry or the bearings of the spindle change and all degrees of freedom are defined. You can deactivate the automatic updating in the settings. In this case there is an additional refresh button in the geometry area that is highlighted if the results need updating.



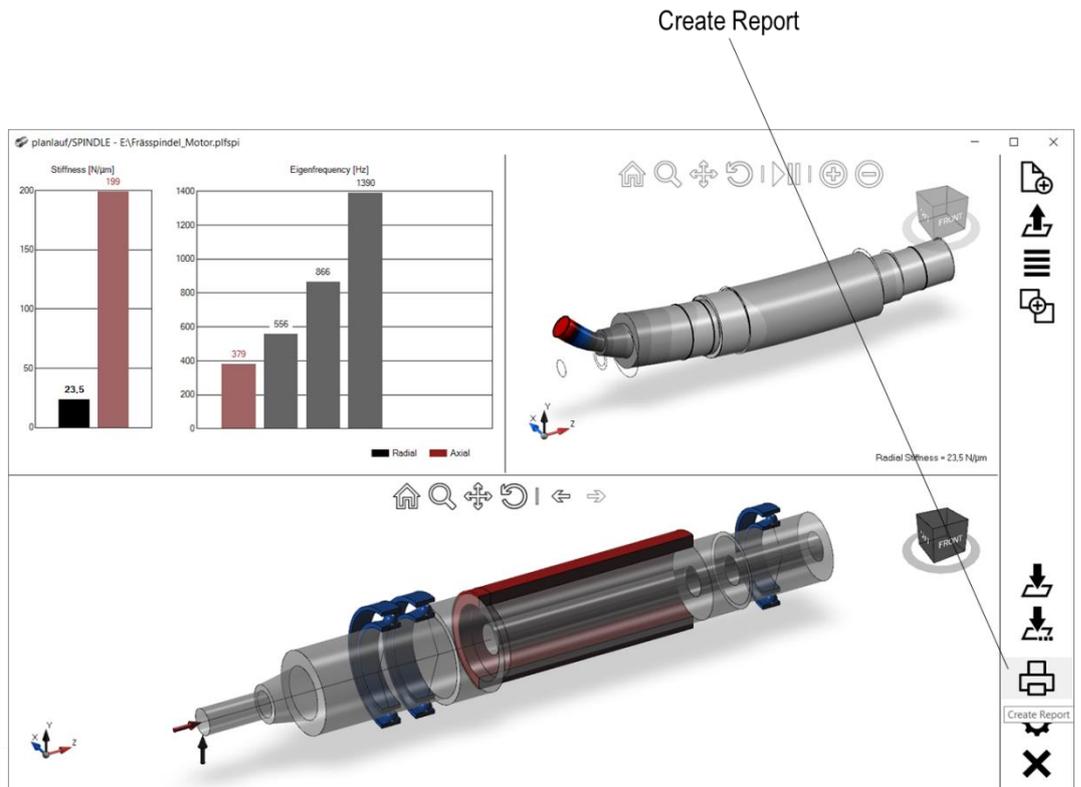


The results are shown in the top half of the window. If the option “Frequency Response Function” is chosen the radial FRF (black) and the axial FRF (red) are displayed. Click on the small circles in the diagram to display the deformation or mode shape on the right.

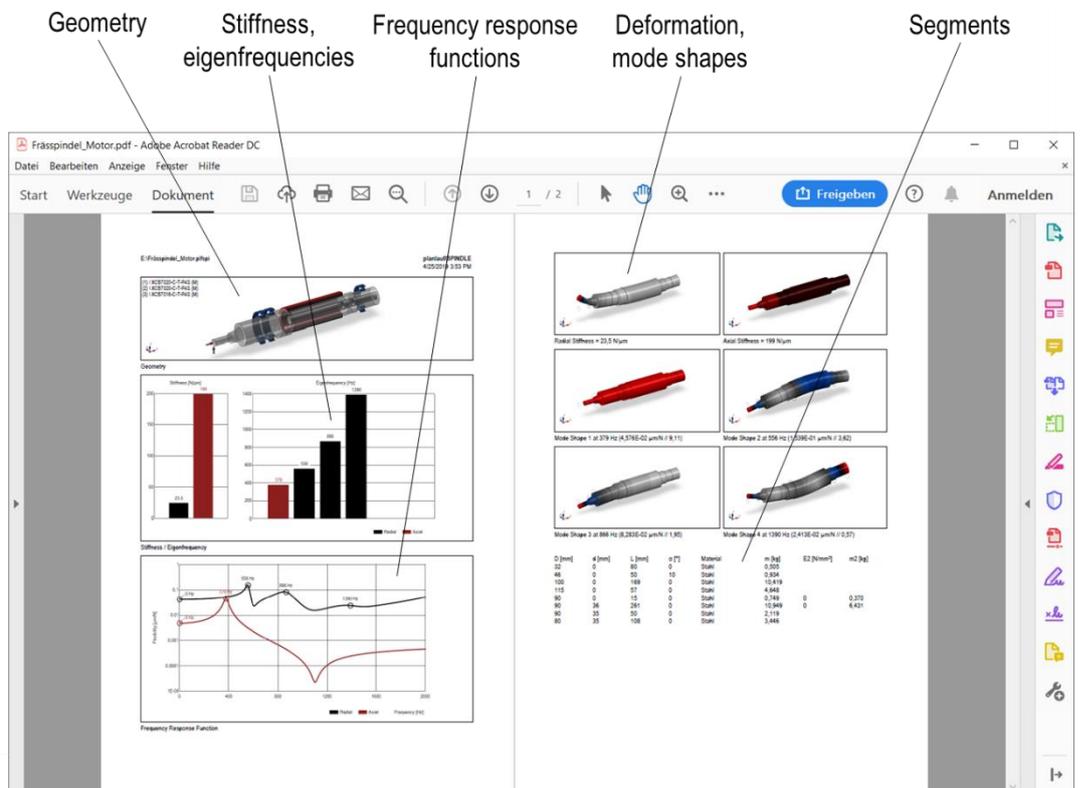
The flexibility is shown on a logarithmic scale and its value at eigenfrequencies is shown in the animation area. Display the phase diagram and the grid lines of the logarithmic scale with the commands of the context menu.

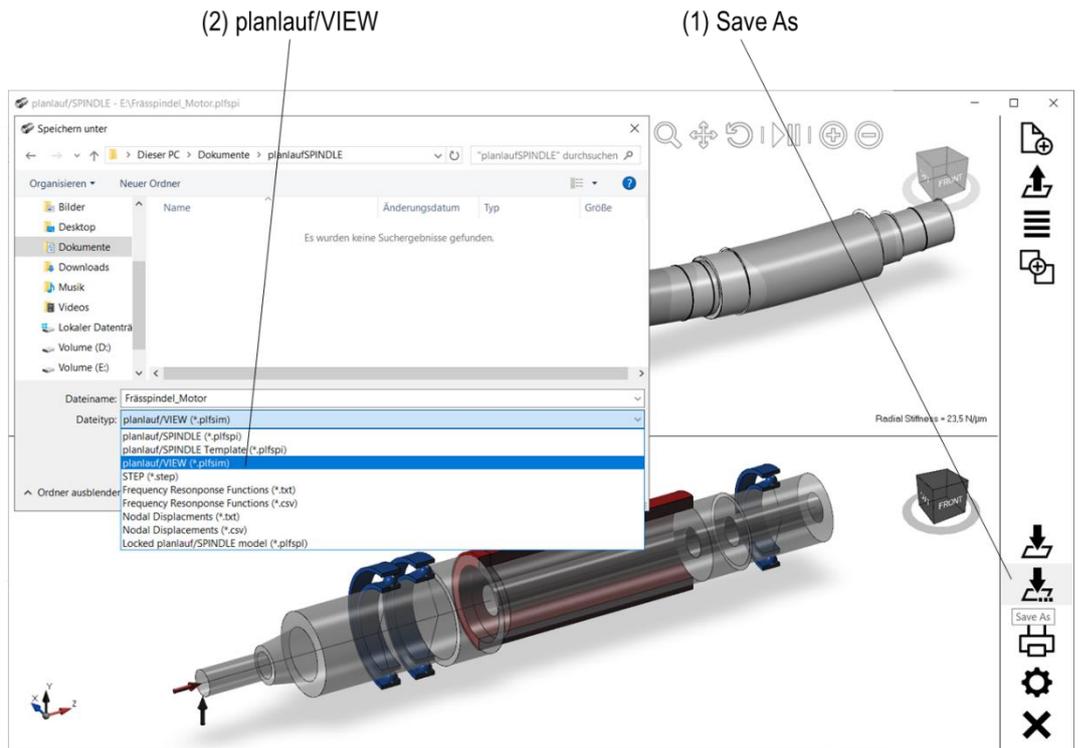


Static deformations and mode shapes are shown in the animation area. Use the symbols to increase/decrease the deformation factor and to start/stop the animation.

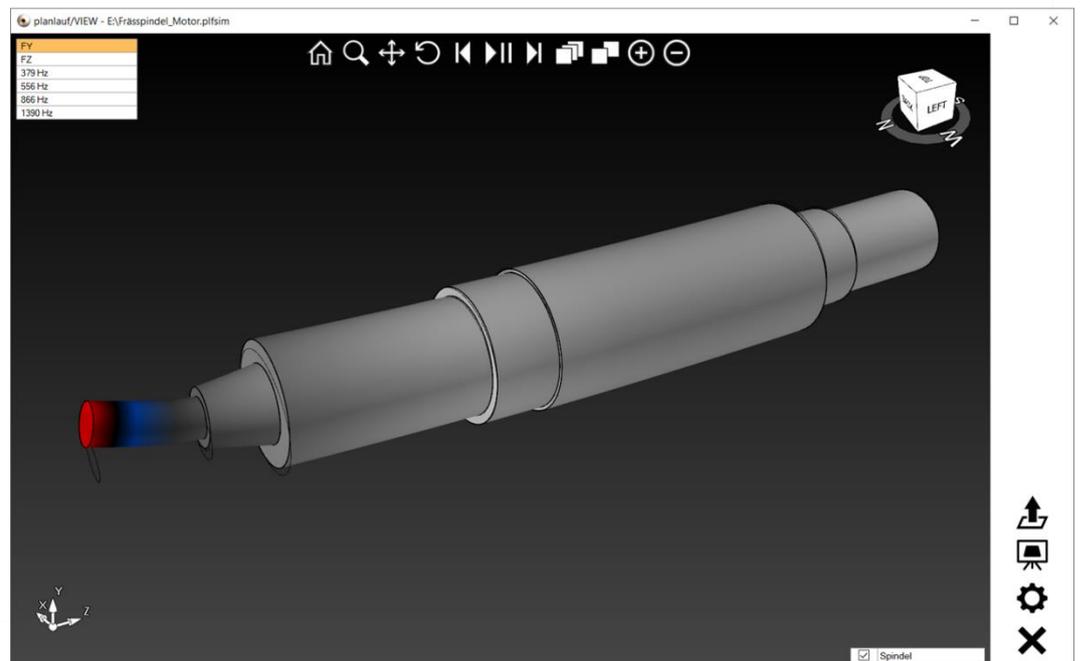


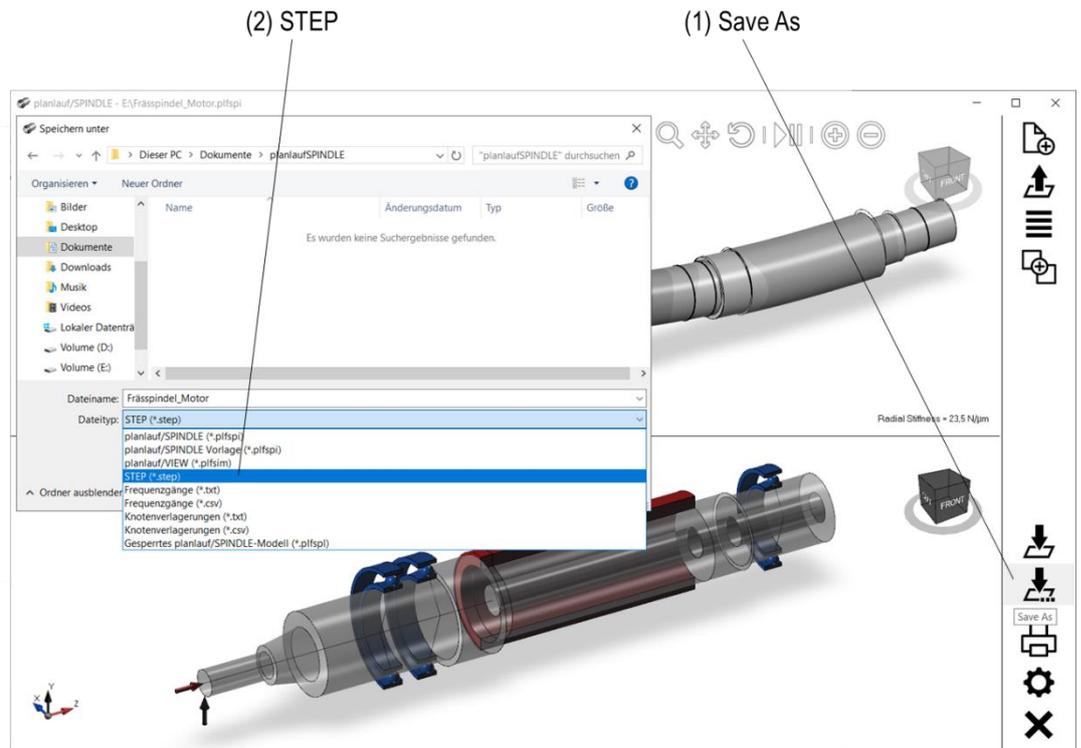
Document the results in a PDF file by clicking on the “Create Report” button. This report includes a view of the geometry, the stiffness values and the eigenfrequencies, the frequency response functions, the deformation and mode shape images and a table of the segments. 3D views in the report correspond to the views in the geometry and animation area.



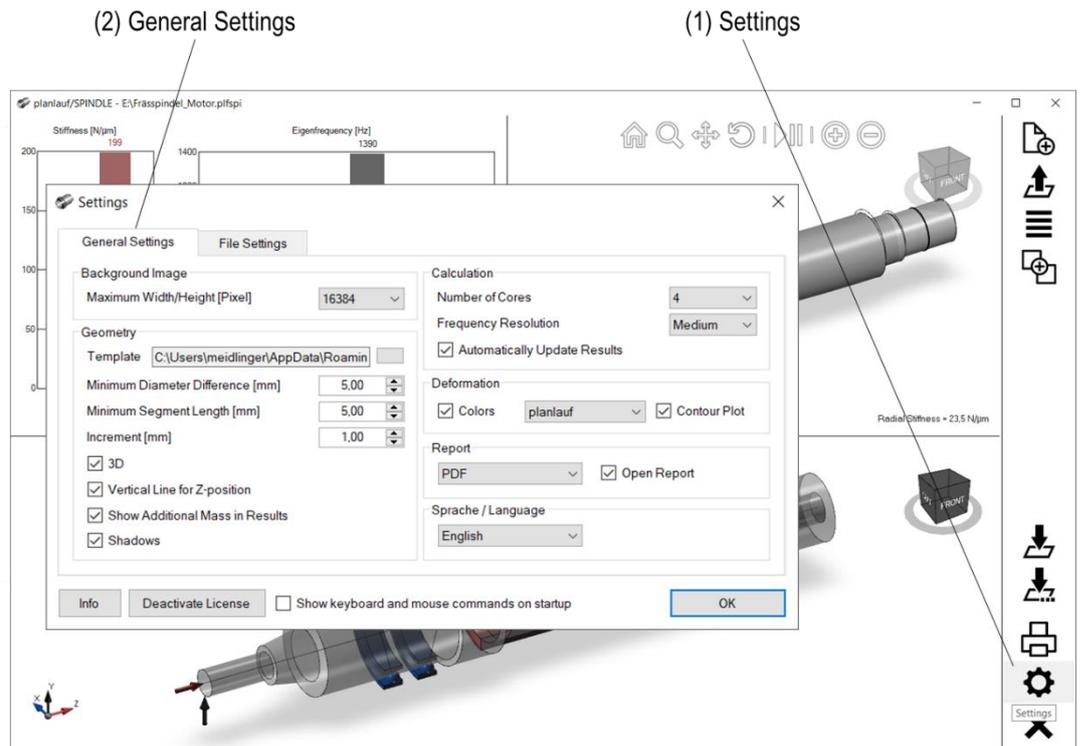


Export the results to a planlauf/VIEW model which can easily be distributed (button “Save As” and file type “planlauf/VIEW”). planlauf/VIEW is our free software to visualize all simulation and measurement results and can be downloaded at: <http://www.planlauf.com/de/software/planlaufview/>.





Export the geometry as a STEP file (button “Save As” and file type “STEP”). The file includes the spindle geometry, the additional masses and the bearings.



The settings can be shown and changed with the “Settings” command. The **general settings** refer to the software itself, the file settings are saved to the file.

The **maximum width/height of the background image** allows to resize images to fit into the graphics card's video memory.

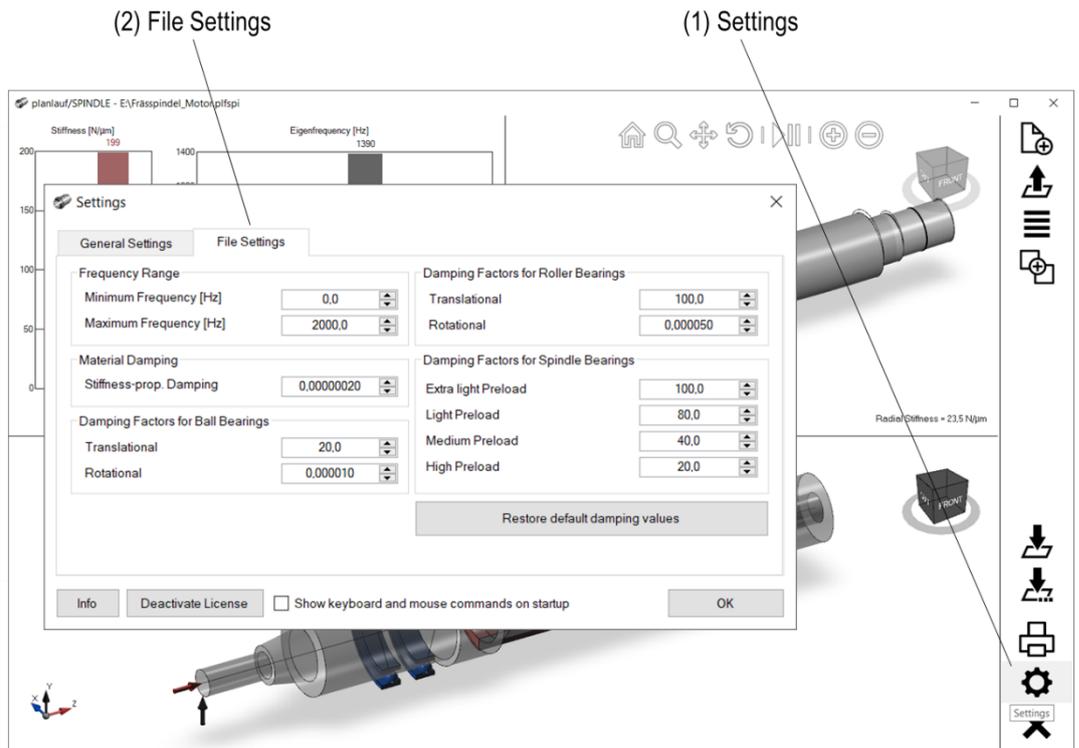
The **minimum diameter difference and segment length** define values that are kept while dragging the geometry. Changing values in the segment table is not affected by this setting. The **increment** is the step size for the geometry changes.

The default view in the geometry and animation area can be set by the home symbol or by a double-click with the middle mouse button. If **3D** is disabled, the default view is the side view and rotation of the model is disabled. The **vertical line for the Z-position** and **additional masses** can also be hidden.

The **number of cores** defines how many CPU cores are used by planlauf/SPINDLE for the calculation of the frequency response functions. Choose a **frequency resolution** option which suits your preference between speed and accuracy. The accuracy at the eigenfrequencies is usually good enough even for the coarse resolution. Disable the **automatic result updating** if the model is huge or your hardware's performance is poor. In this case, you can refresh the results with the button in the geometry area.

The **deformation** in the animation area can be highlighted by colors. There are three color scales and a **contour plot** option available.

The file format for the **report** can either be PDF or Microsoft Word. If the “Open Report” option is checked, the report is automatically opened after it has been created.



In the file settings you can adjust the **frequency range** or damping values for different bearing types. The default values are the result of many comparisons between simulated and measured results and are suitable for most spindles.

If you want to use customized damping values or materials for all new spindles, you can adjust the values and save the file as a **template** ("Save As" > "planlauf/SPINDLE Template (\*.plfspi)"). Choose this file in the general settings and restart planlauf/SPINDLE.