Jan 2023

Power Flow and System Deflection Analysis

MASTA 12.0

Classification: Public

SMART MANUFACTURING TECHNOLOGY LTD, WILFORD HOUSE, 1 CLIFTON LANE, WILFORD, NOTTINGHAM, NG11 7AT
tel. +44 (0)115 941 9839

www.smartmt.com

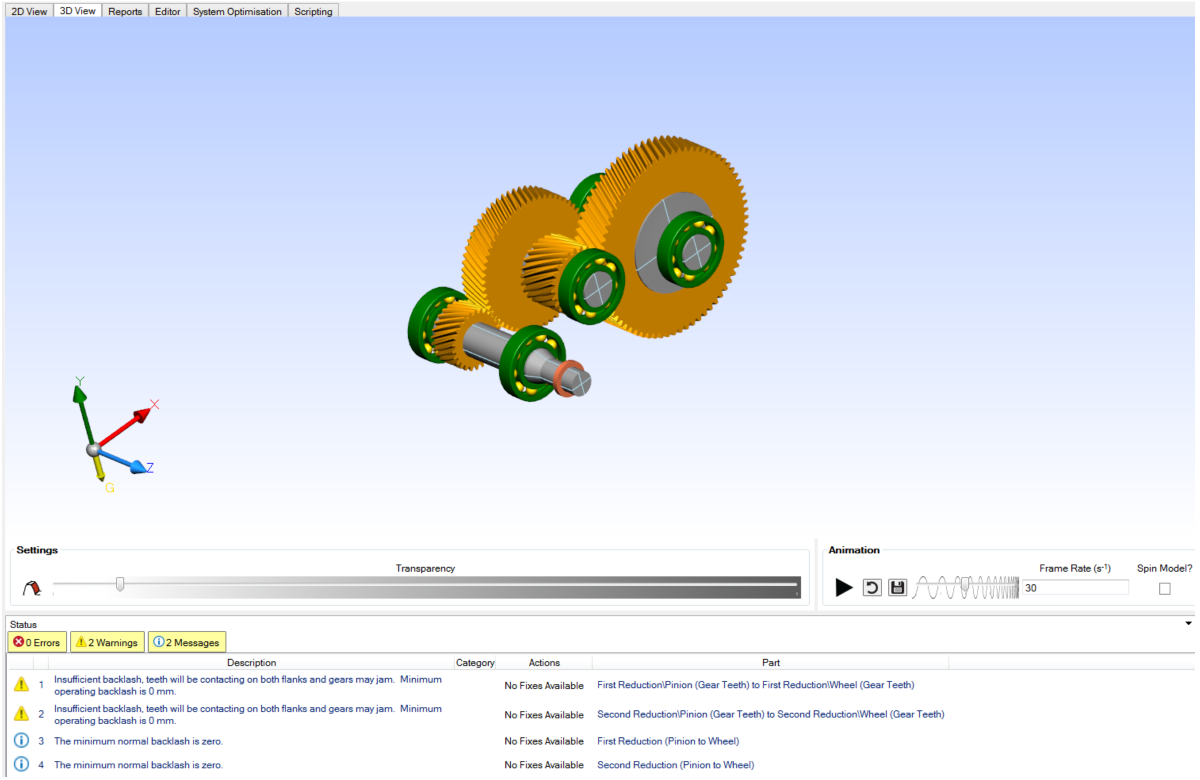
MASTA Tutorial Overview

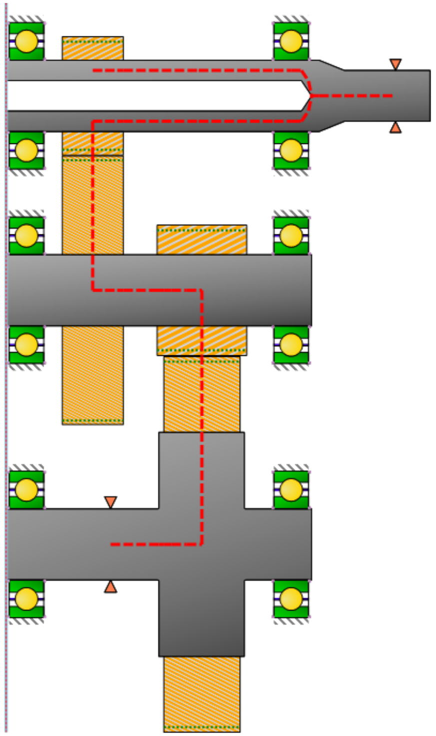
- For sections 4 onwards, you can use the model you have built in section 3. Alternatively there is a pre-built model ‘EV Gearbox.Masta’ that you can load in order to complete the remaining tasks

Power Flow

Power Flow - Introduction

- Power flow is primarily used to check your design and load cases since it does not account for misalignments which affect gear ratings.
- Power flow solves the Power = Torque x Speed equation for all components and connections





Power Flow - Interface

SMT

Power Flow Mode

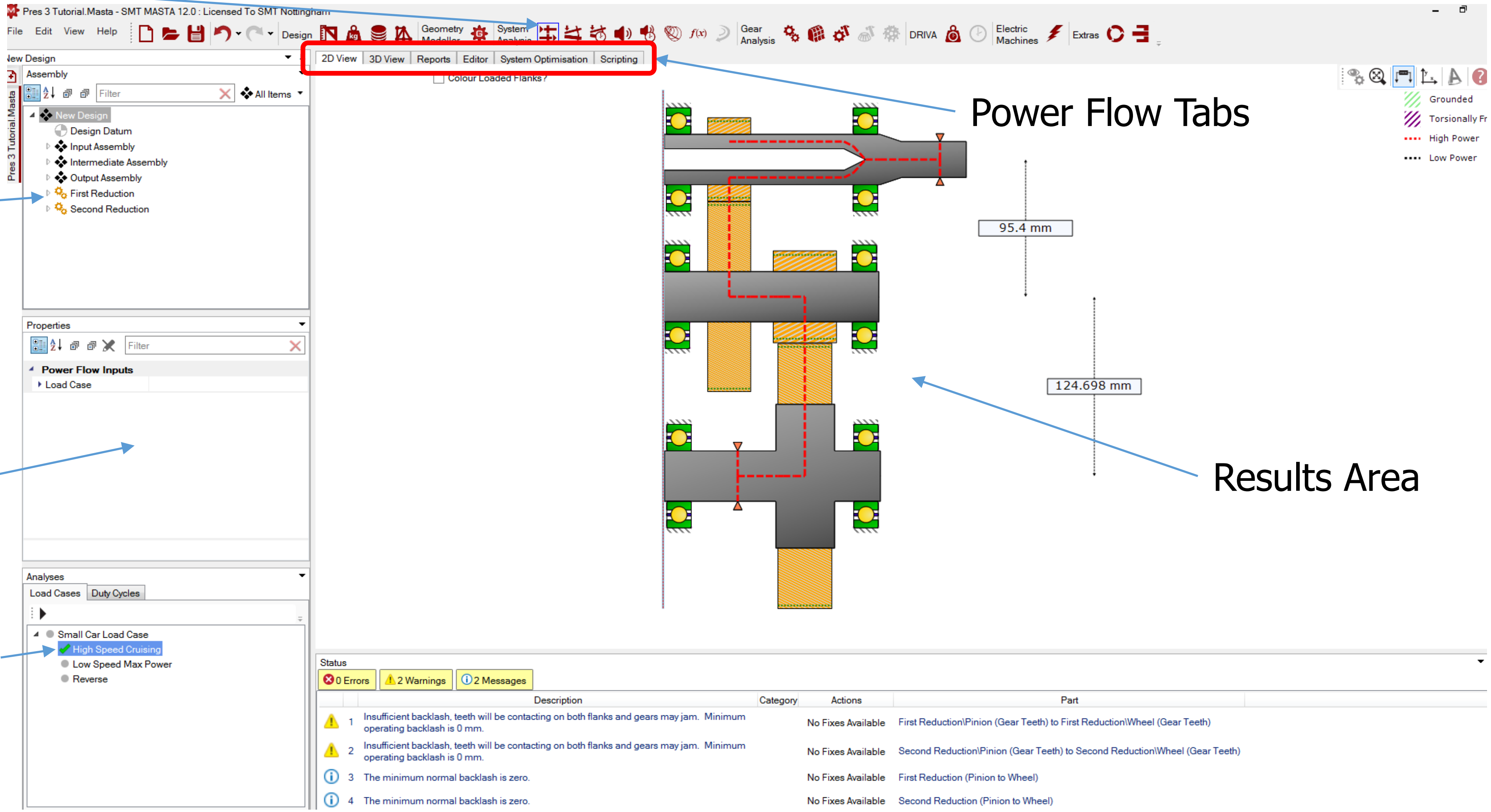
Assembly View

Properties Grid

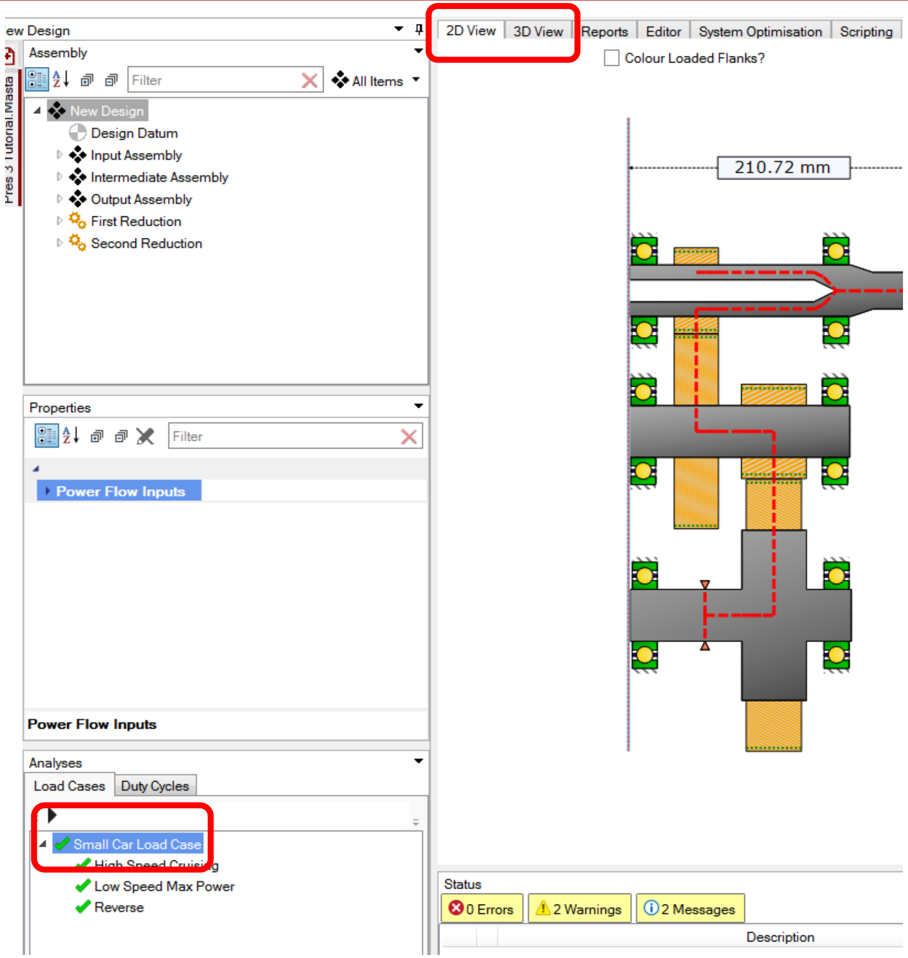
Load Cases & Duty Cycles

Power Flow Tabs

Results Area

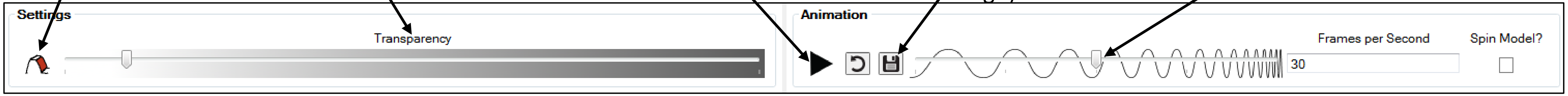


Power Flow - Interface



- Click on the 2D View tab, and select and run a load case to see the transmission power through the two gear stages
- Then click on the 3D View tab and click play to see your drive train operate
- *Low frame rates may make some components appear to be rotating in the wrong direction, to obtain the smoothest video, select twice the refresh rate of your monitor
- Reduce the animation speed

Colour Loaded Flanks
Model Transparency
Play
Save Animation (.wmv or. gif)
Animation Speed



Power Flow - Reports

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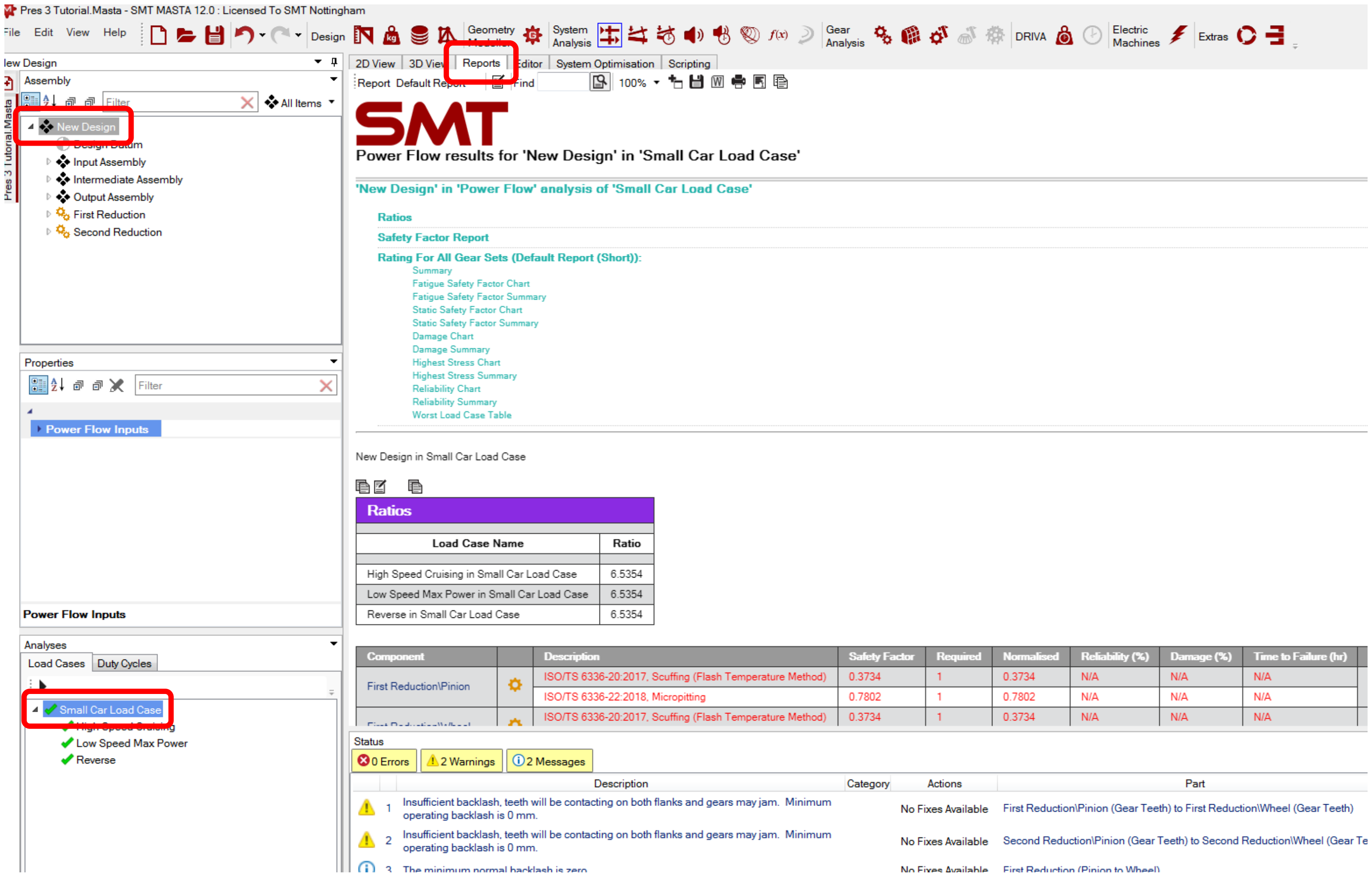


- Click on the Reports tab to see the results of the load case you ran
- The report gives rating results including damage and safety factors for the gear pairs according to ISO 6336, DIN 3990 or AGMA 2101-D04 standards, not including any misalignment.
- Select the top level of the assembly view and the load case you just ran to generate a power flow analysis summary report
- A more detailed report of individual gear sets can be viewed by selecting the gear set in the assembly tree

Power Flow - Reports

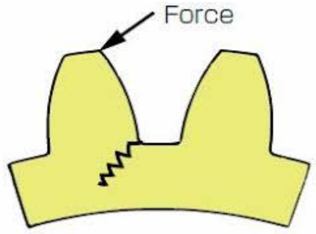
- Scroll down or click on 'Rating For All Gear Sets' to see the fatigue and static safety factors of the two gear pairs
- Each safety factor is associated with bending and contact durability
- Bending failure is characterised by shearing at the gear root
- Contact failure is characterised by surface damage on the gear face width
- Data may be copied by clicking the icon shown below 'copy to clipboard'

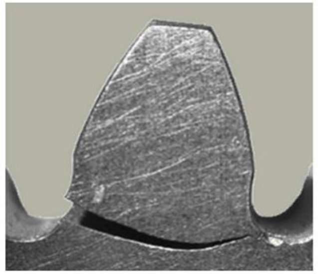
Safety Factor Report
Power Load Details
2D Drawing
Rating For All Gear Sets (Default Report (Short)):
- Summary
- Fatigue Safety Factor Chart
- Fatigue Safety Factor Summary
- Static Safety Factor Chart
- Static Safety Factor Summary
- Damage Chart
- Damage Summary
- Highest Stress Chart
- Highest Stress Summary
- Reliability Chart
- Reliability Summary
- Worst Load Case Table

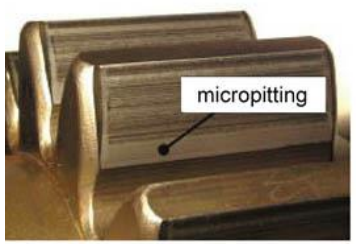
Component Passing Orders
Component Speeds

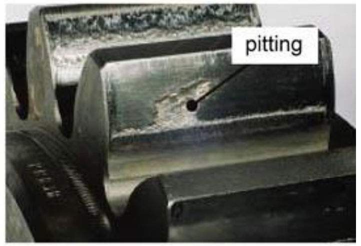
Fatigue Safety Factor Summary

Name	Safety Factor (Bending)		Safety Factor (Contact)	
	Left Flank Rating	Right Flank Rating	Left Flank Rating	Right Flank Rating
1st Gear Stage\Pinion	2.0193	50	1.3221	50
1st Gear Stage\Wheel	2.0187	50	1.4079	50
2nd Gear Stage\Pinion	50	1.8747	50	1.2769
2nd Gear Stage\Wheel	50	1.7211	50	1.3875



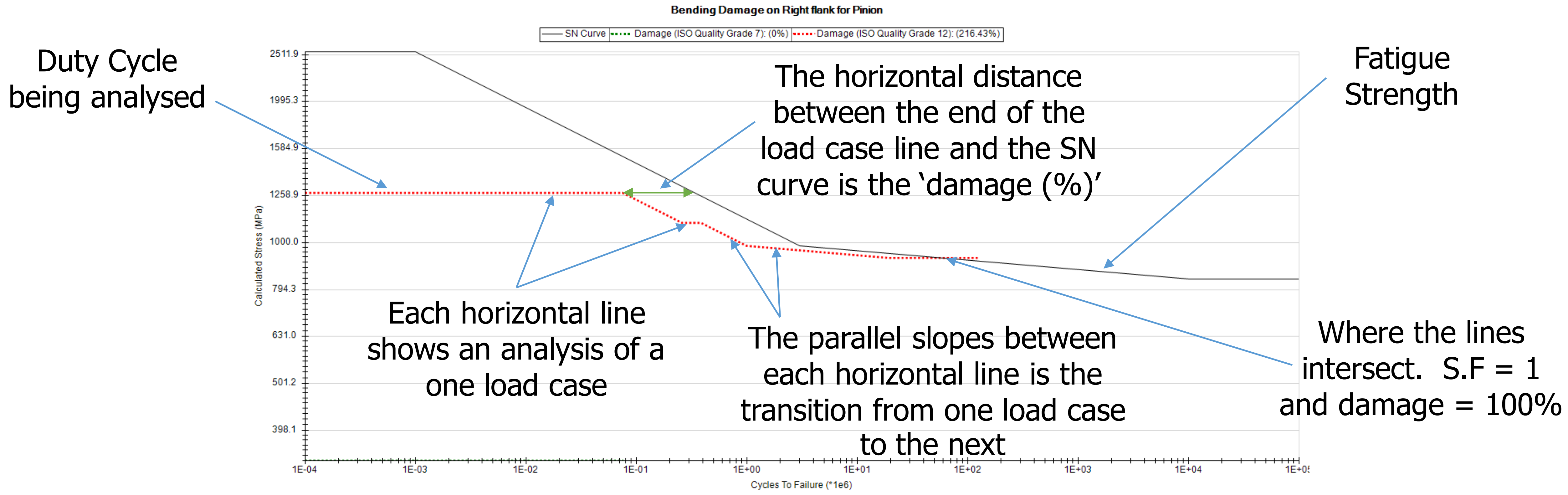






Power Flow - Fatigue and Static Safety Factors

- The safety factor indicates how far away the applied stress is from the maximum stress
- Fatigue safety factors are calculated from the fatigue strength and the stress amplitude



- Static safety factors are based on the tensile yield strength of the material

Power Flow - Fatigue and Static Safety Factors

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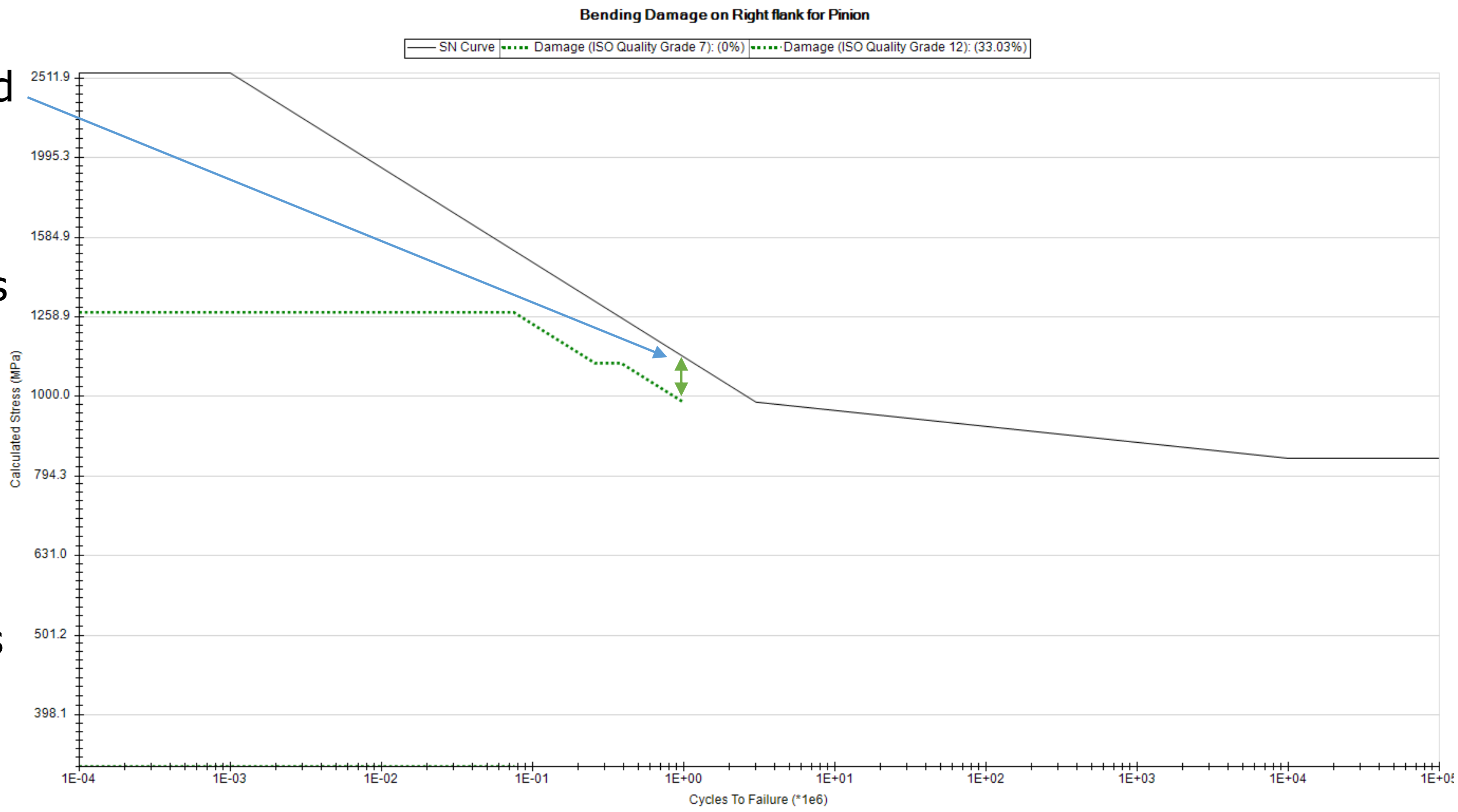
The ratio of the end of the duty cycle curve and the SN curve at the given number of cycles is the safety factor (S.F)

Damage curve is green if failure doesn't occur (S.F is < 1)



Power Flow - Duty Cycle Analysis

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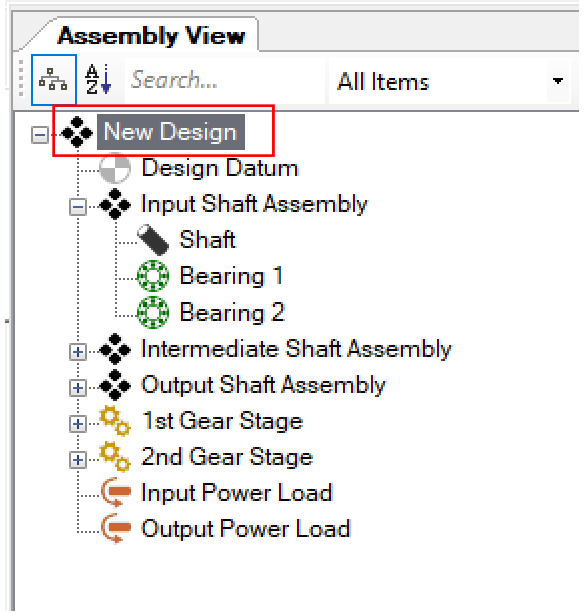
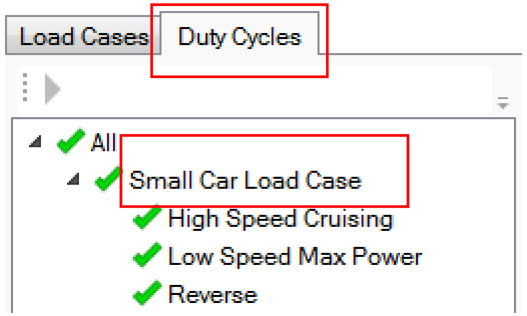
- Select the top level in the assembly tree, select the duty cycle tab, select the top level of the duty cycle and run the duty cycle
- Then copy the fatigue and static safety factors into your spreadsheet

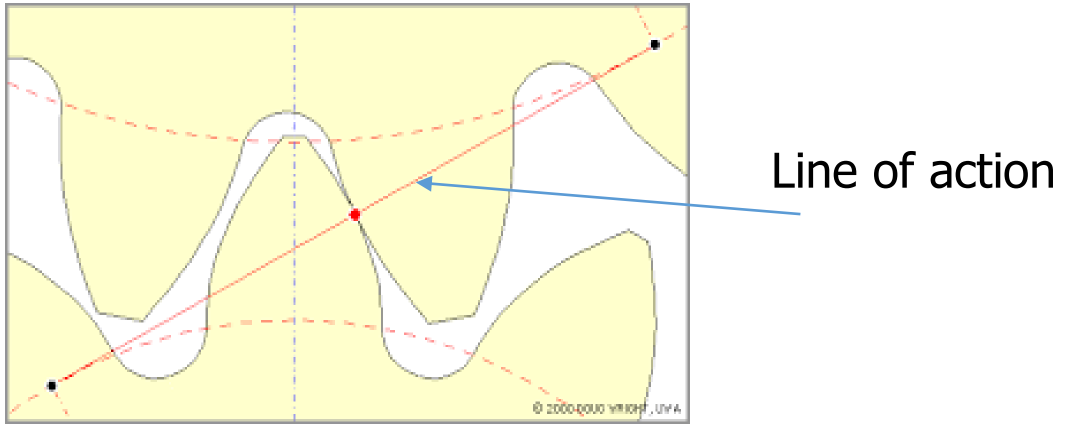




System Deflection

System Deflection - Introduction

- System deflection takes misalignment into account and solves the 'force = stiffness x deflection' equation for all components and connections
- Misalignment in MASTA is defined in the transverse plane as a displacement along the line of action (where the gears are in mesh during rotation)
- The system deflection mode can be used to obtain component deflections, shaft stress, gear loads/misalignments/ratings (to ISO 6336, AGMA 2101 - D04 or DIN 3990 standards for cylindrical gears), as well as bearing loads/misalignments/ratings (to ISO 76, ISO 281 and ISO/TS 16281 standards)



System Deflection - Interface

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System Deflection Mode

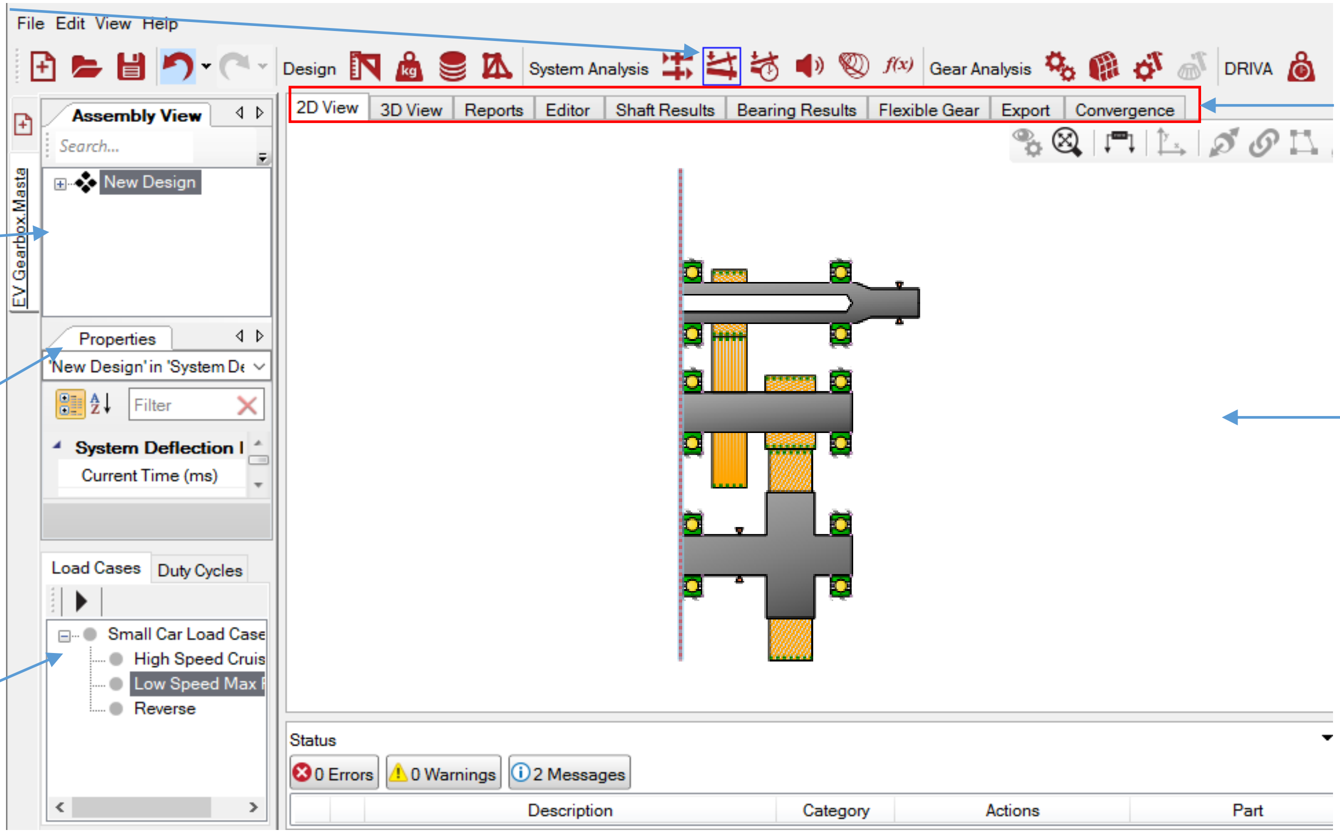
System Deflection Tabs

Assembly View

Properties Grid

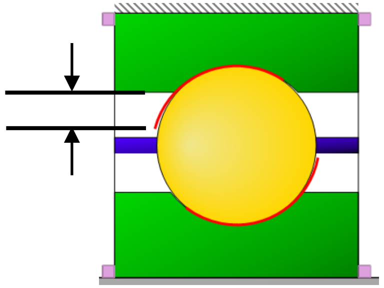
Results Area

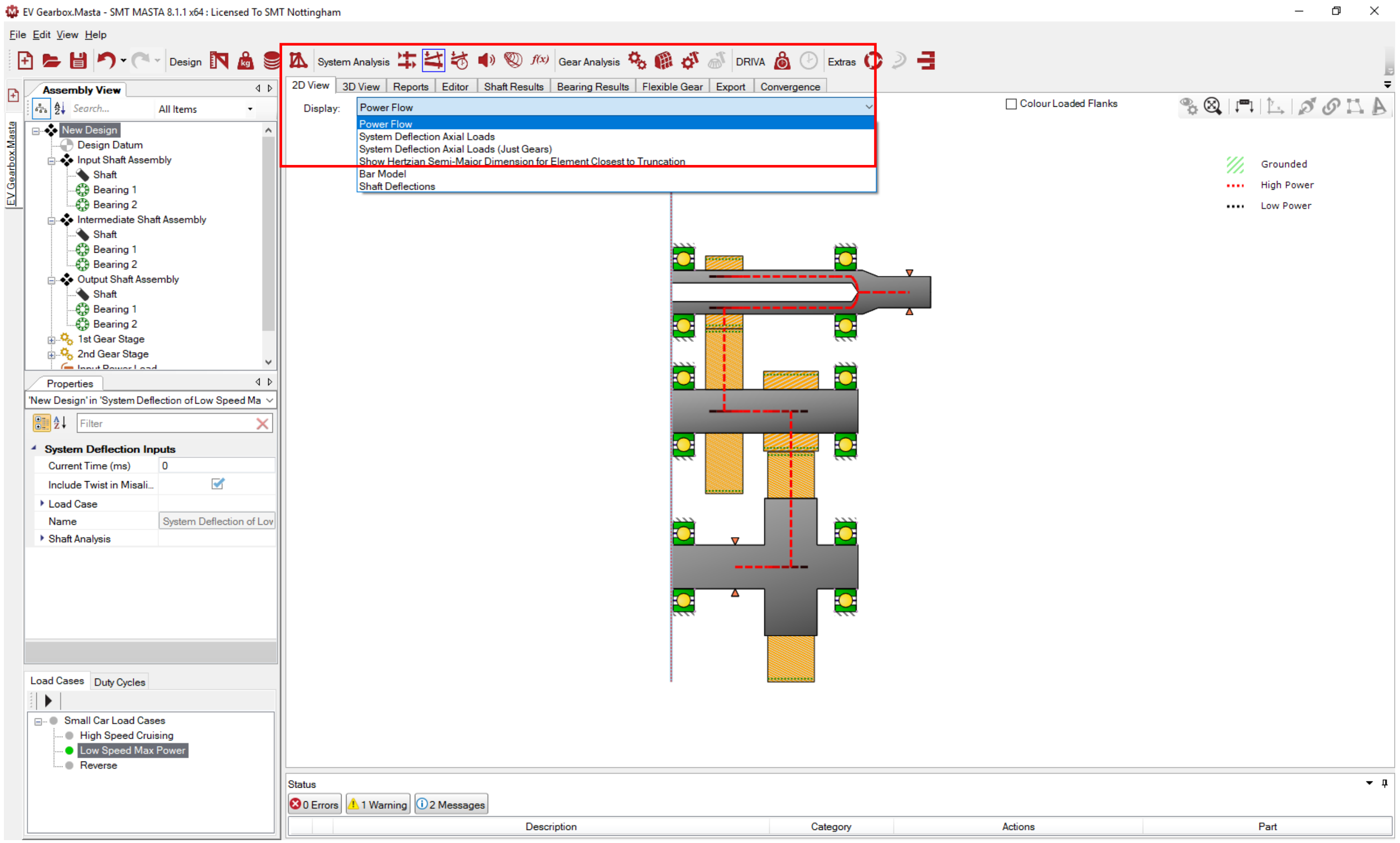
Load Cases & Duty Cycles



System Deflection – Interface

- Select the 2D view tab and run a load case
- Click on the display drop-down box to view different types of visual results
- Power flow, system axial loads, and bearing elements that are closest to truncation may prove useful to identify potential problems in your drivetrain
  - Truncation = when the theoretical Hertzian contact area of the element goes beyond the bearing race groove





System Deflection – Interface

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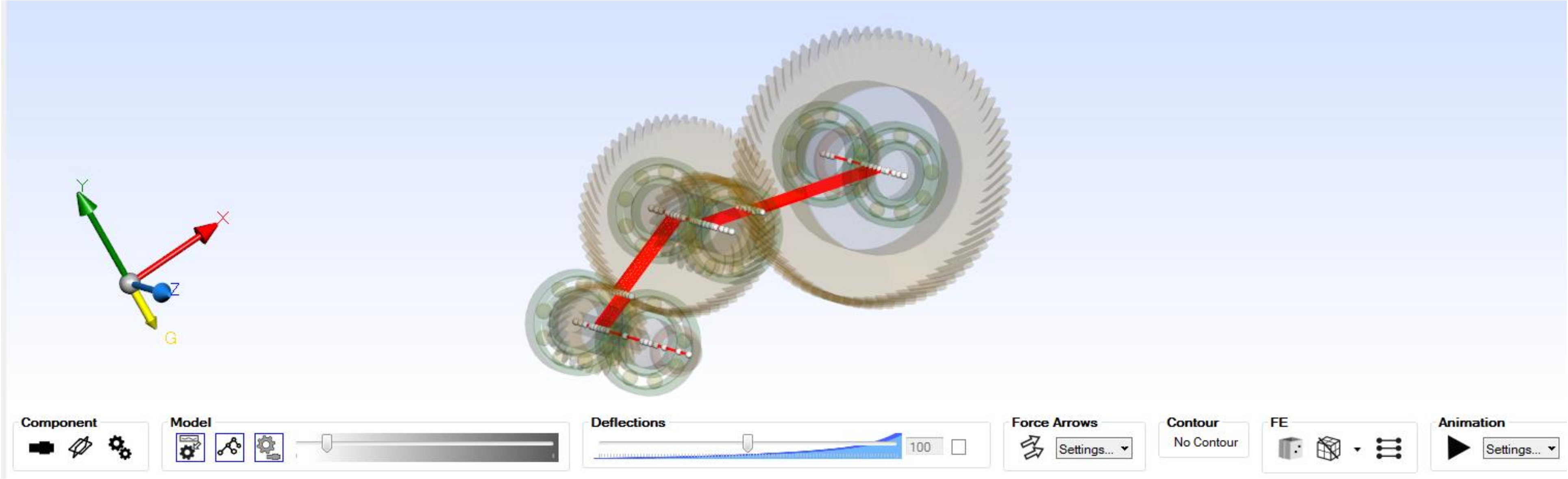
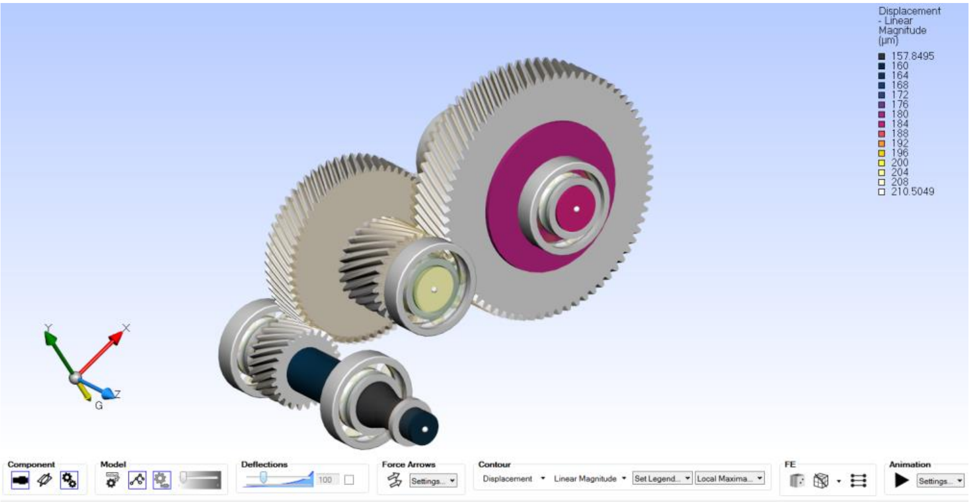
- Select the 3D View tab to view the system deflections, ensuring that just a single load case is selected



- Have a play around with the display settings to get a feel for the options available
- Try playing an animation of the deflections, using the play button on the right-hand side

System Deflection – Interface

- Switch on 'solid shafts', 'solid components' and 'transparent model' with the buttons in the bottom left corner
- The 'no contour' drop-down menu is now selectable
  - Select 'Displacement' → 'Linear Magnitude' to view the magnitude of the deflections of each shaft
- Adjust the displacement scale to see the directions of the displacement in relation to original position shown by the transparent model
- To view a sub-assembly or individual components, double-click on the sub-assembly or component, respectively, in the component tree in the assembly view

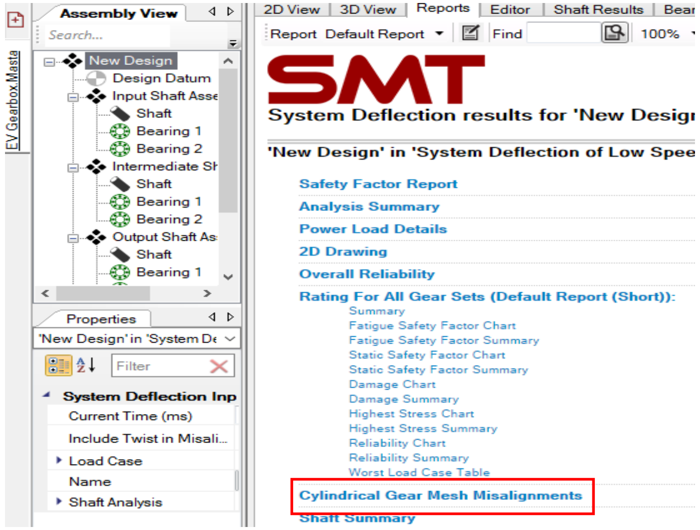


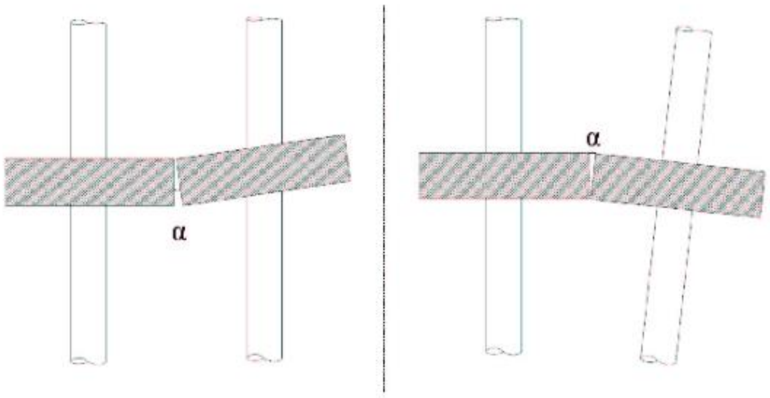
System Deflection - Reports

- Select the reports tab, the top level of the assembly tree and the load case you ran to generate a summary report of the system
- Reports for the shafts and bearings are now available

System Deflection – Gear Mesh Misalignment

- Clicking on ‘Cylindrical Gear Mesh Misalignments’ will show you the misalignments of the individual gears for each gear set, and the total equivalent misalignment





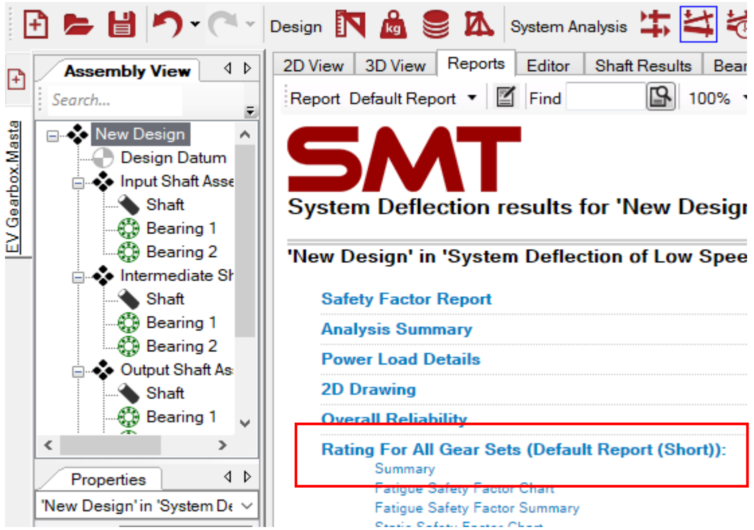
Example of gear misalignment

Cylindrical Gear Mesh Misalignments

Name	Gear Mesh Contact Status	Gear A	Gear B		Total Equivalent Misalignment for Rating (μm)	Gear A Equivalent Misalignment for Rating (μm)	Gear B Equivalent Misalignment for Rating (μm)
		Name					
					ⓘ	ⓘ	ⓘ
					f_{sh}		
First Reduction (Pinion to Wheel)	Left Flank	Pinion	Wheel		3.9304	2.8284	-1.102
Second Reduction (Pinion to Wheel)	Right Flank	Pinion	Wheel		6.3027	-2.3187	-7.4159

System Deflection – Gear Ratings

- Click on 'Ratings For All Gear Sets' to see the fatigue and static gear ratings
- Run the full duty cycle on system deflection and copy the gear ratings into your spreadsheet
- Task: now compare your power flow and system deflection gear ratings in your spreadsheet. What effect did misalignment have on the gear ratings?



Fatigue Safety Factor Summary

Name	Safety Factor (Bending)		Safety Factor (Contact)	
	Left Flank Rating	Right Flank Rating	Left Flank Rating	Right Flank Rating
1st Gear Stage\Pinion	1.9485	50	1.2936	50
1st Gear Stage\Wheel	1.948	50	1.3776	50
2nd Gear Stage\Pinion	50	1.791	50	1.2425
2nd Gear Stage\Wheel	50	1.6443	50	1.3501

System Deflection – Shaft Rating

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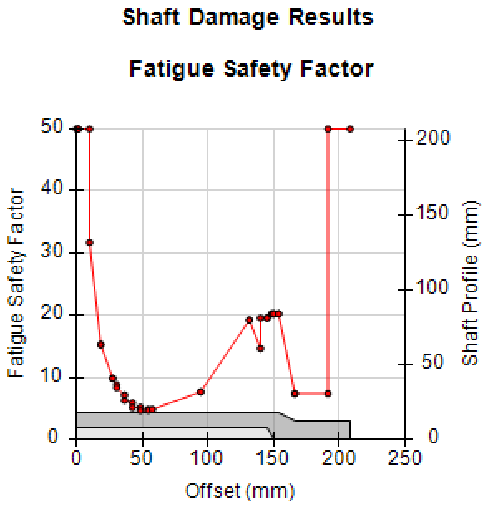
- Select the top level of the duty cycle and click on 'Shaft Fatigue Safety Factor Summary Table' in the main Reports tab to see the fatigue and static safety factors of all shafts
- The Shaft Results tab provides a more detailed analysis of individual shafts:
  - Select the input shaft and select 'Fatigue Safety Factor' in the drop-down menu
  - This display shows the value of the safety factor along the shaft profile

2D View | 3D View | Reports | Editor | Shaft Results | Bearing Results | Flexible Gear | Export | Convergence

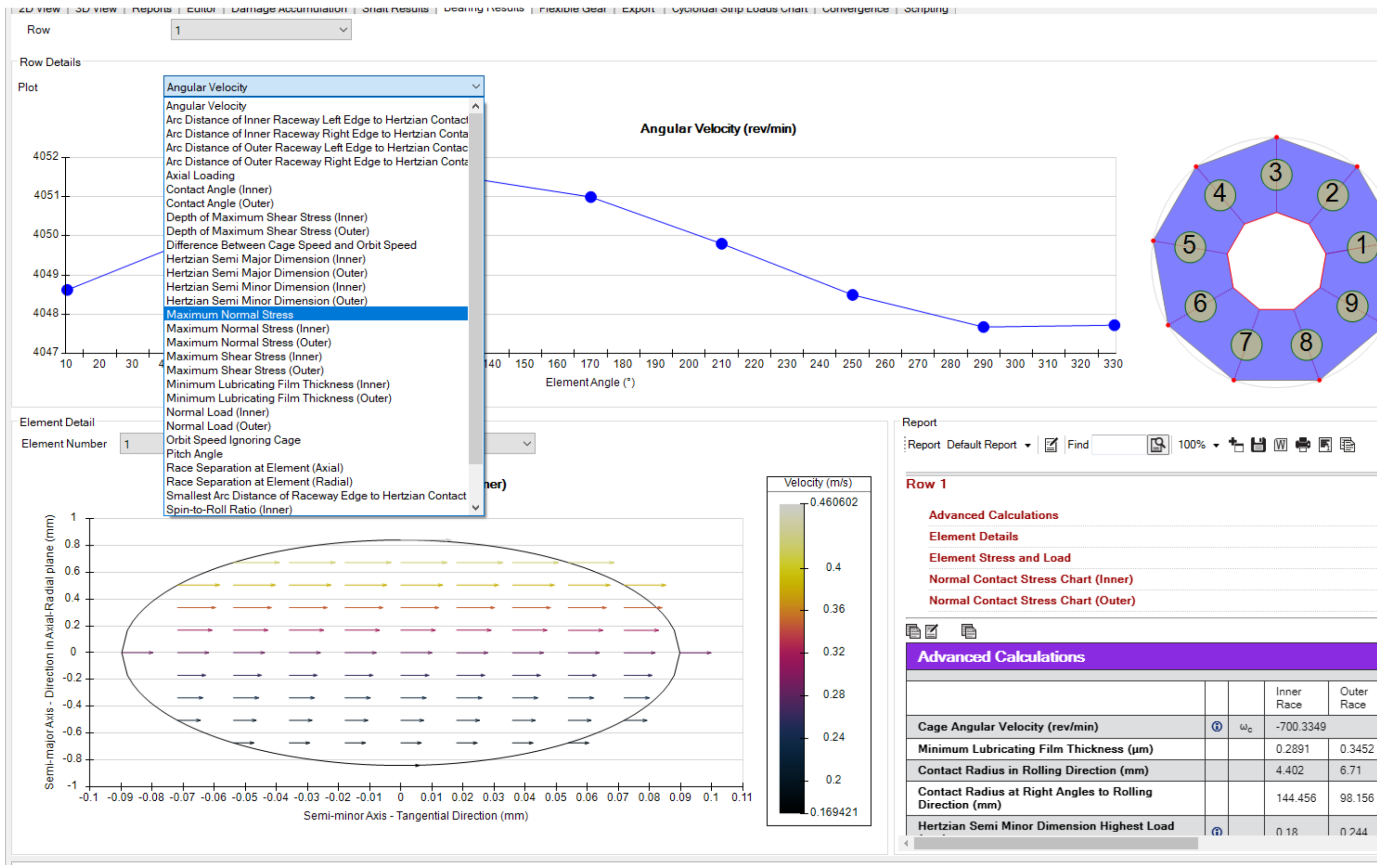


Fatigue Safety Factor

Offset (mm)	
0	50
1.5	50
1.5	50
10	50
10	31.7152
18.5	15.2667
18.5	15.2667
27.55	9.8355
27.55	9.8355
30.55	8.7979
30.55	8.324
36.55	7.1562
36.55	6.2673
42.55	5.8972
42.55	5.1241
48.55	5.1504
48.55	4.6217

Display: Fatigue Safety Factor

System Deflection – Bearing Ratings



- Select the top level of the duty cycle and click on 'Bearing Summary Table' in the main Reports tab to see the fatigue and static safety factors of all bearings
  - Static: ISO 76
  - Fatigue: ISO 281 and ISO 16281
- Select the 'Bearing Results' tab and select a bearing and a specific load case
  - Change the plot display to 'Maximum Normal Stress' to see how the stress is distributed among the bearing elements
  - Scroll down to see the contact patterns on the inner and outer bearing races

Additional Tasks

- By only considering the gears, how can gear ratings be improved?
  - Hint: Think about ways to improve allowable bending and contact stresses
- For the next tasks:
  - Any changes to the model will need to be done in the design mode
  - Make a note of the parameters and their values you change so that you can change them back afterwards – or make multiple saves
- Reduce the axial displacement of the intermediate shaft
  - Hint: Consider changing the gear hands and the helix angle
  - Why does changing the helix angle affect the axial forces?
- In system deflection mode, run the duty cycle and look at the shaft ratings in the Reports tab. Are there any shaft safety factors below 1?
  - If so:
    - Which shaft?
    - Find where the safety factor falls below 1 in Shaft Results
    - Try to increase the safety factor ≥1

Additional Tasks

- Relevant training videos include:

System Deflection - smartmt (wistia.com)

System Deflection Mode - Overview - smartmt (wistia.com)

All videos in ‘System Deflection Mode’ dropdown are relevant

Training videos can be accessed by pressing (F1 > Tutorial Videos) in MASTA.

Next task…

- Please now work through the document:
  5. Gear Macro Geometry

Thank you for your attention

SMT

SMART MANUFACTURING TECHNOLOGY LTD
WILFORD HOUSE, 1 CLIFTON LANE
WILFORD
NOTTINGHAM, UK
NG11 7AT

tel. +44 (0) 115 941 9839 | **fax.** +44 (0) 115 958 1583

www.smartmt.com

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