SOLFINS

MECHANICAL ANALYSIS AND OPTIMISATION OF FRONT ROLLER ASSEMBLY

FEA and FATIGUE report

Abstract

The purpose of this calculation is to check the minimal life cycle of the rollers. Life requirement for Front Roller Assembly is 15 years. The central part of the Gantry which can rotate ±180 degrees, is supported on bearing units with three rollers each. High precision requirements for the structure rule out any plastic deformations in the area of contact. In order to achieve a large contact area and a uniform distribution of contact stress, a barrel shape for the rollers is proposed. Static and fatigue analysis using finite element method (FEM) was performed to optimize the roller shape and camber radius of the rollers in order to get maximal life cycle of the Assembly.

June 2010

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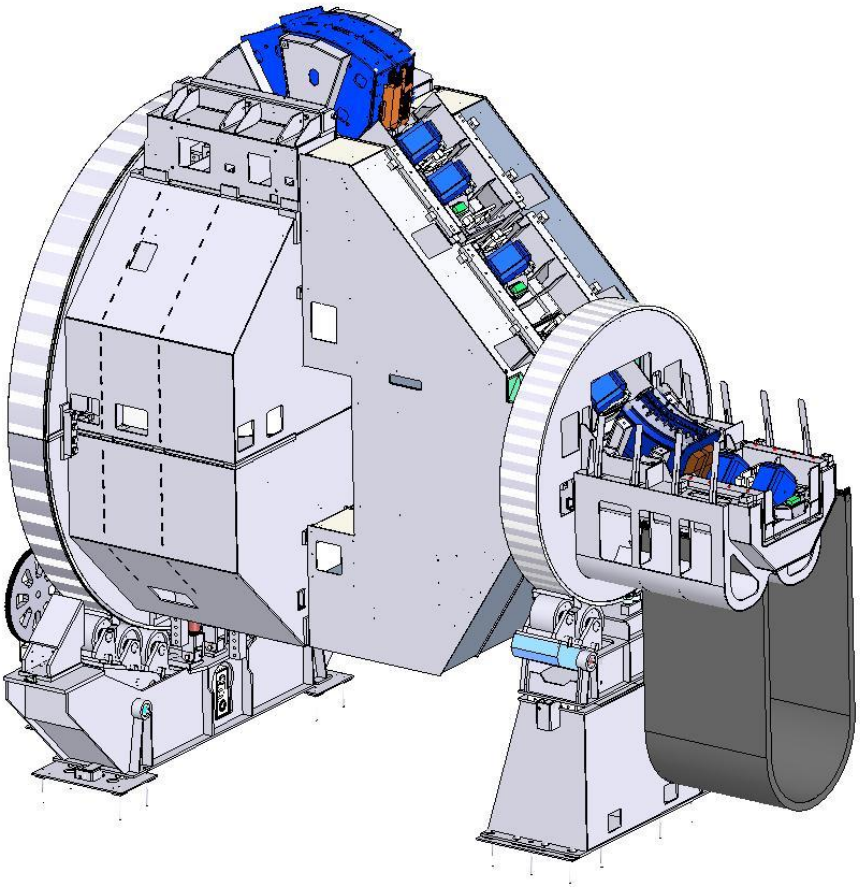
1. INTRODUCTION

The purpose of this calculation is to check the minimal life cycle of the rollers. Life requirement for Front Roller Assembly is 15 years. The central part of the Gantry which can rotate ±180 degrees, is supported on bearing units with three rollers each. High precision requirements for the structure rule out any plastic deformations in the area of contact. In order to achieve a large contact area and a uniform distribution of contact stress, a barrel shape for the rollers is proposed. Static and fatigue analysis using finite element method (FEM) was performed to optimize the roller shape and camber radius of the rollers in order to get maximal life cycle of the Assembly.

Gantry construction is set to Front Roller Assembly from front side, and to Rear Roller Assembly from back side. Front and Rear Roller Assemblies allows rotation of the whole Gantry construction. Total weight of the Gantry construction is about 130 tons. According to calculation of load distribution and Bearing calculations we can conclude that the more loaded part of the construction is Front Roller Assembly with belonging rollers.



1.1. Fatigue Requirements

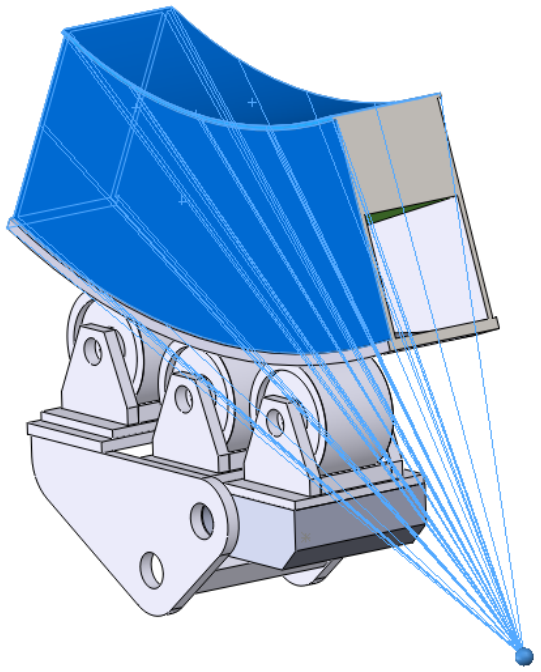
The 15 year life requirement for the assembly:

- (4 patients / hour) x (12 hours / day) x (7 gantry rev / patient) x (365 days / year) x 15 years = 1,839,600 revolutions of big ring.
- The ratio between Ring and Roller diameter is 12.96 (7000mm/540mm), so the number of revolutions for rollers is approximately: n=19.96 * 1839600 ≈ 24000000 revolutions and this number is used in Fatigue study as number of cycles.

2. GEOMETRY AND MATERIAL PROPERTIES

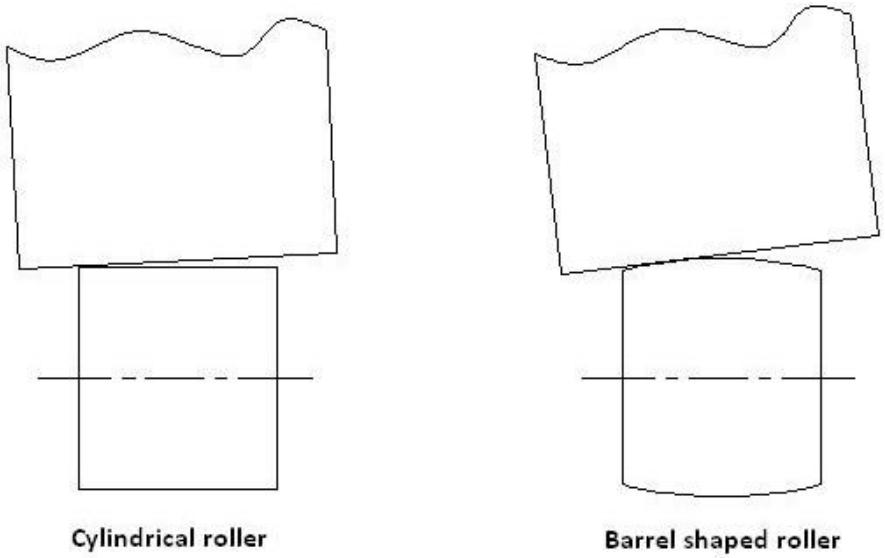
2.1. Simplifications

The geometry of the Front Roller Assembly and simplifications for the purpose of calculations are shown at the below picture. The missing components are replaced with distributed mass applied to the ring segment. The uneven influence of distributed mass on the ring surfaces causing unevenly distributed load on the surface of the rollers.



Influence of distributed mass on the Gantry Ring

Described assumption causing the following misalignment of the axis of rotation:



This is the most unfavorable case when we have stress concentration on the roller edge. Changing the shape of the roller to the barrel shape stress concentration should be avoided. All these cases will be considered in the following analysis.

Front Roller assembly is symmetrical and one half of the assembly is removed for clarity and to reduce computational requirements.

Since experimental results for the S-N curves are based on bend loading, other types of loading like shear, and torsion are accounted with Load factor: **0.8**

Surface of the rollers and ring is assumed to be machined (milling and turning) with Surface quality factor: **0.93**

Big parts can have material imperfections, and this is accounted with Size factor: **0.8**

Fatigue strength reduction factor(Kf): Kf=0.8x0.93x0.8=0.6

2.2. Material Properties

The same material was used for all contact components(ring and rollers) in the Front Roller Assembly. The material properties are listed in following table:

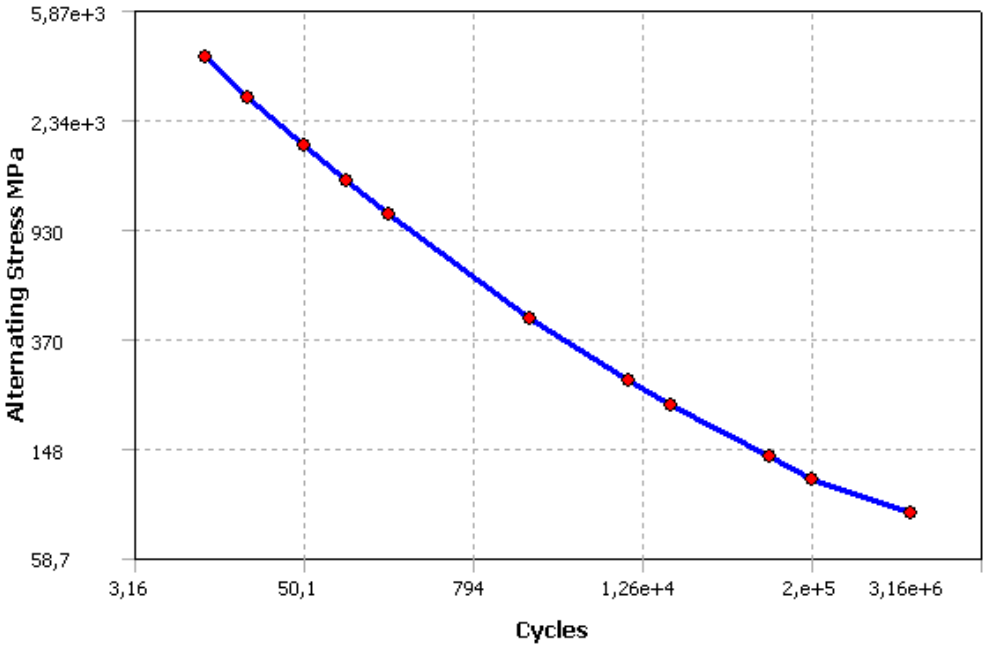
Material Name:	**S355J2G3**
Elastic modulus (N/mm^2)	2,e+005
Poisson's ratio	0.3
Shear modulus (N/mm^2)	7.9e+010
Mass density (kg/m^3)	7800
Tensile strength (N/mm^2)	520
Yield strength (N/mm^2)	355
Thermal expansion coefficient (K)	1.1e-005
Thermal conductivity (W/mK)	6.05
Specific heat (J/kg.K)	434

For all other components was used structural steel 1.0037(S235JR). The material properties are listed in following table:

Material Name:	**1.0037 (S235JR)**
Elastic modulus (N/mm^2)	2.1e+005
Poisson's ratio	0.28
Shear modulus (N/mm^2)	7.9e+010
Mass density (kg/m^3)	7800
Tensile strength (N/mm^2)	355
Yield strength (N/mm^2)	275
Thermal expansion coefficient (K)	1.1e-005
Thermal conductivity (W/mK)	14
Specific heat (J/kg.K)	440

2.3. S-N curves

All fatigue analysis was made upon data from experimental given S-N curve for material 1.0057 (S355 J2G3).



Cycles	Alternating Stress (N/mm ^{2} - MPa)
10000	902
50000	510
1e+005	410
5e+005	250
1e+006	205
5e+006	130
1e+007	108
5e+007	75
1e+008	66

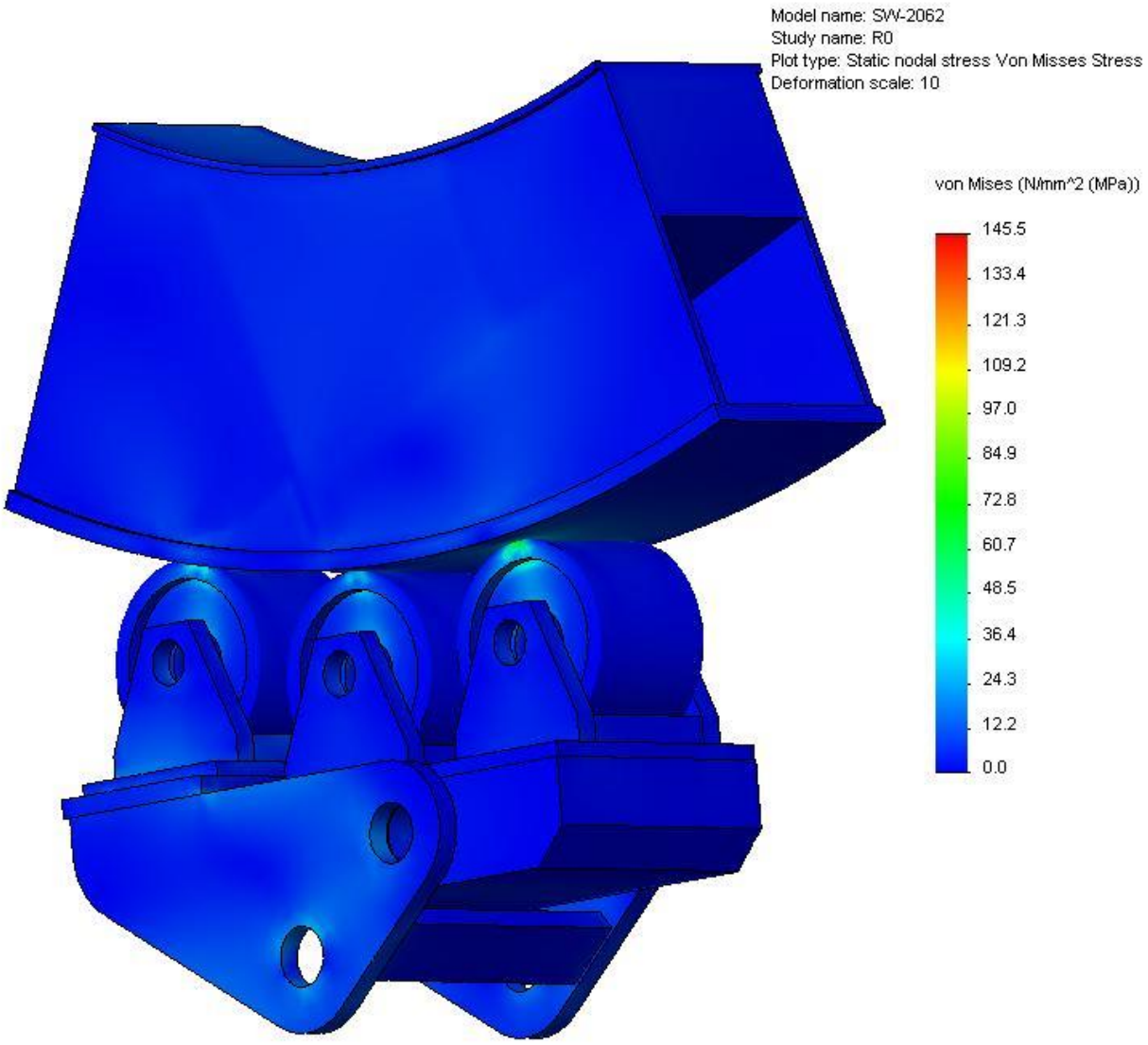
2.4. Mesh information

The mash information is listed in following table:

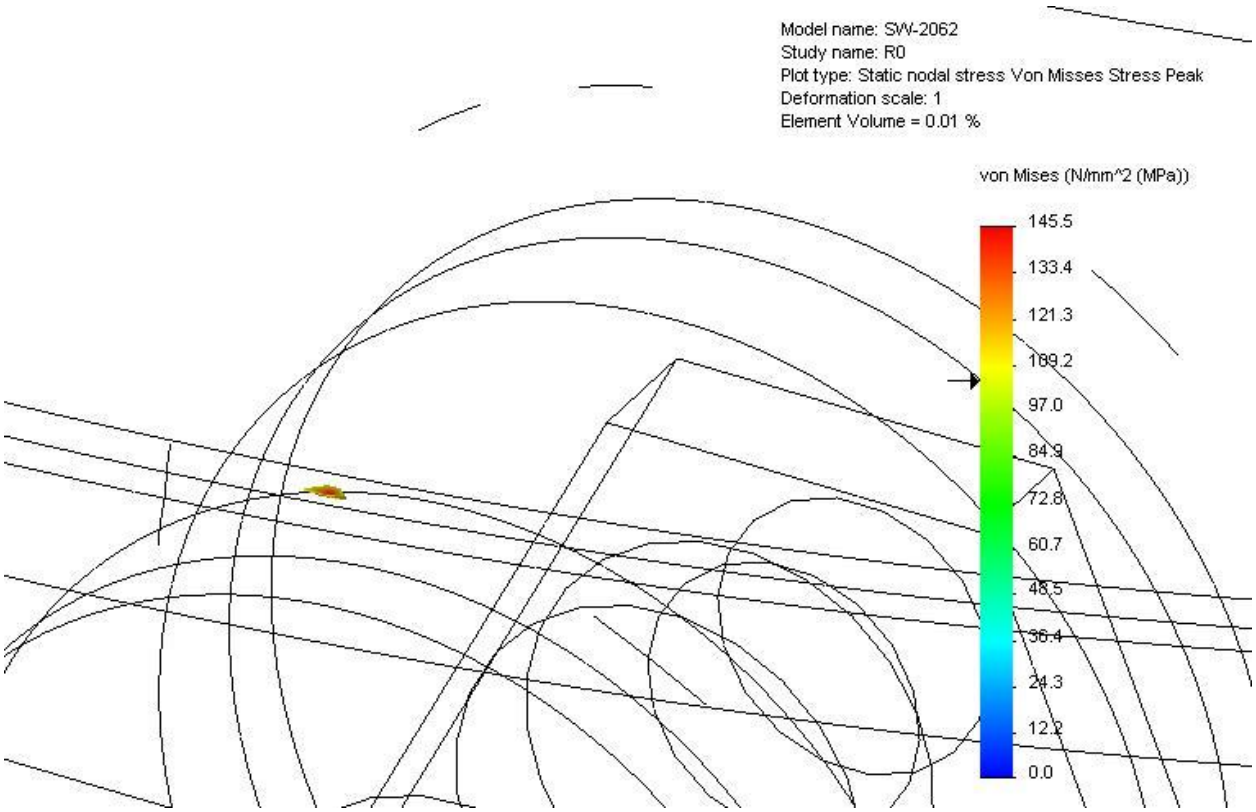
Mesh Type:	Solid Mesh
Mesher Used:	Standard mesh
Jacobian Check:	4 points
Element Size:	25 – 60 mm
Tolerance:	3mm
Quality:	High
Number of elements:	90984
Number of nodes:	161539

3. STRESS ANALYSIS FOR CYLINDRICAL ROLLERS

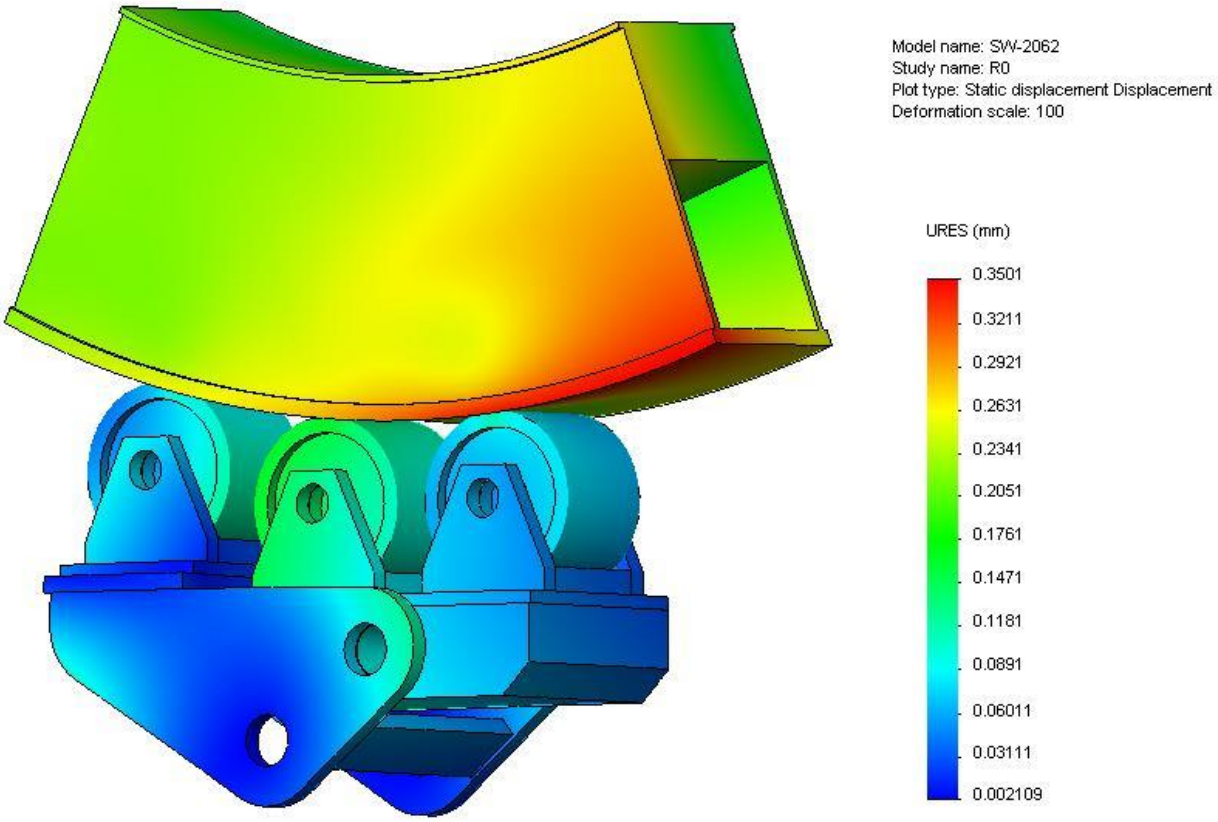
Stress analysis for cylindrical rollers was changed when we compare it with previous one, because we have changed surface contact conditions in order to get much more accurate results of calculation.



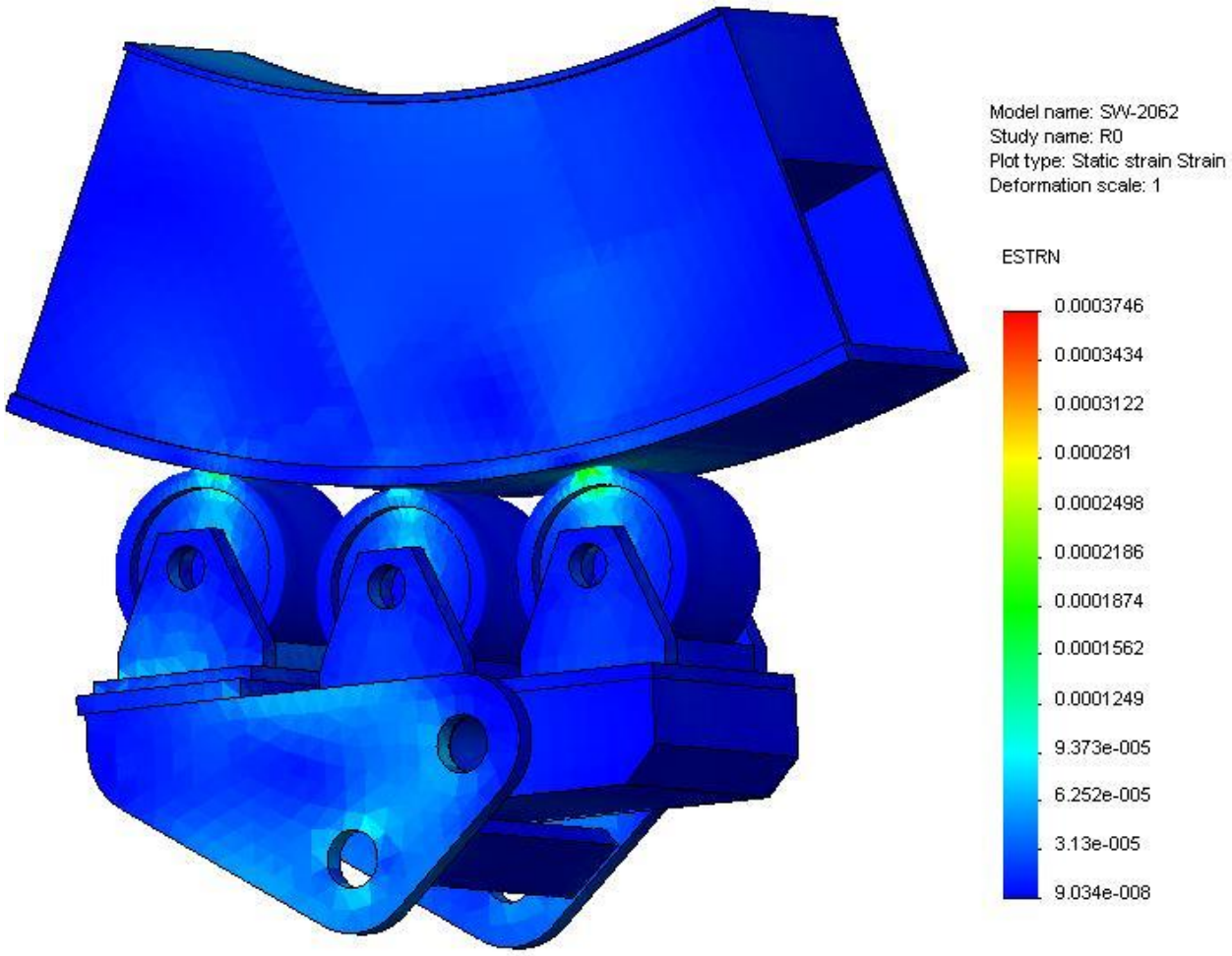
Von Misses Stress



Von Misses Stress Peak



Displacement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Study name: R0
Plot type: Static strain Strain
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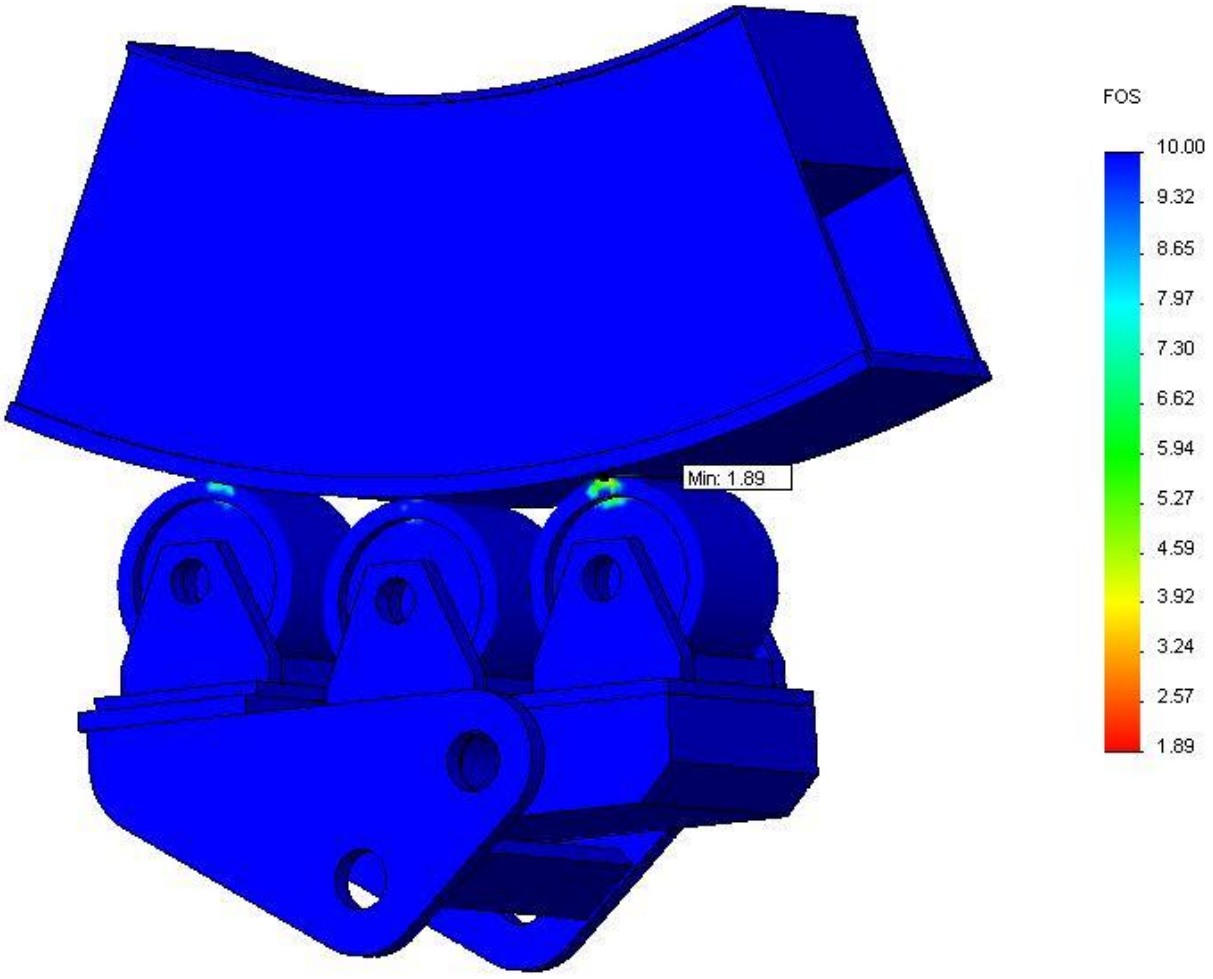
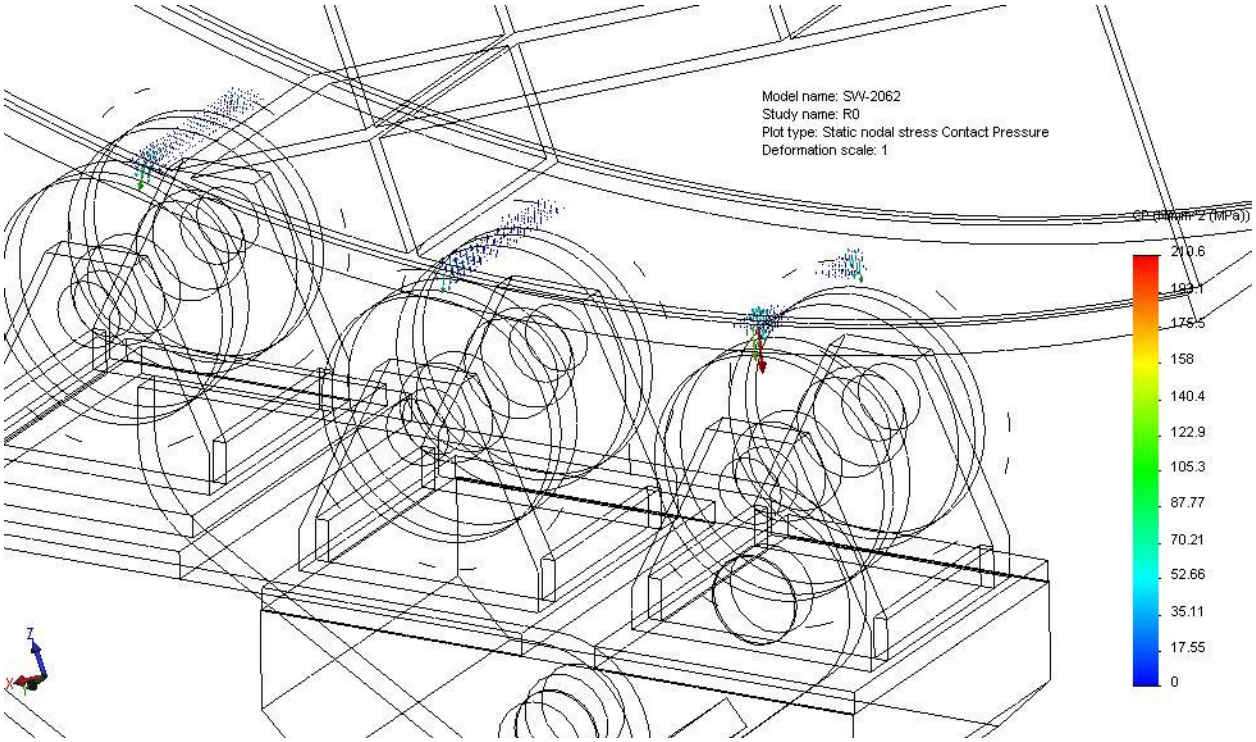
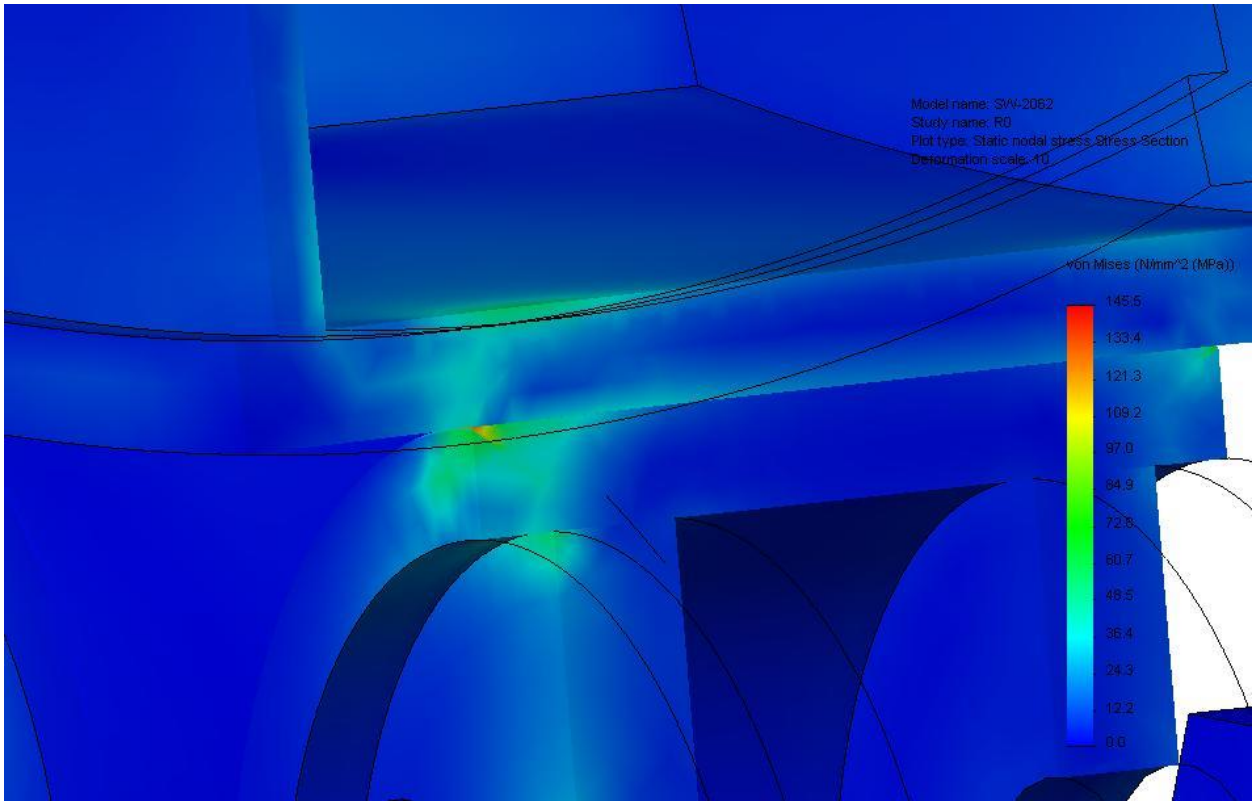
Strain



Factor of Safety



Contact Pressure



Von Misses Stress Section

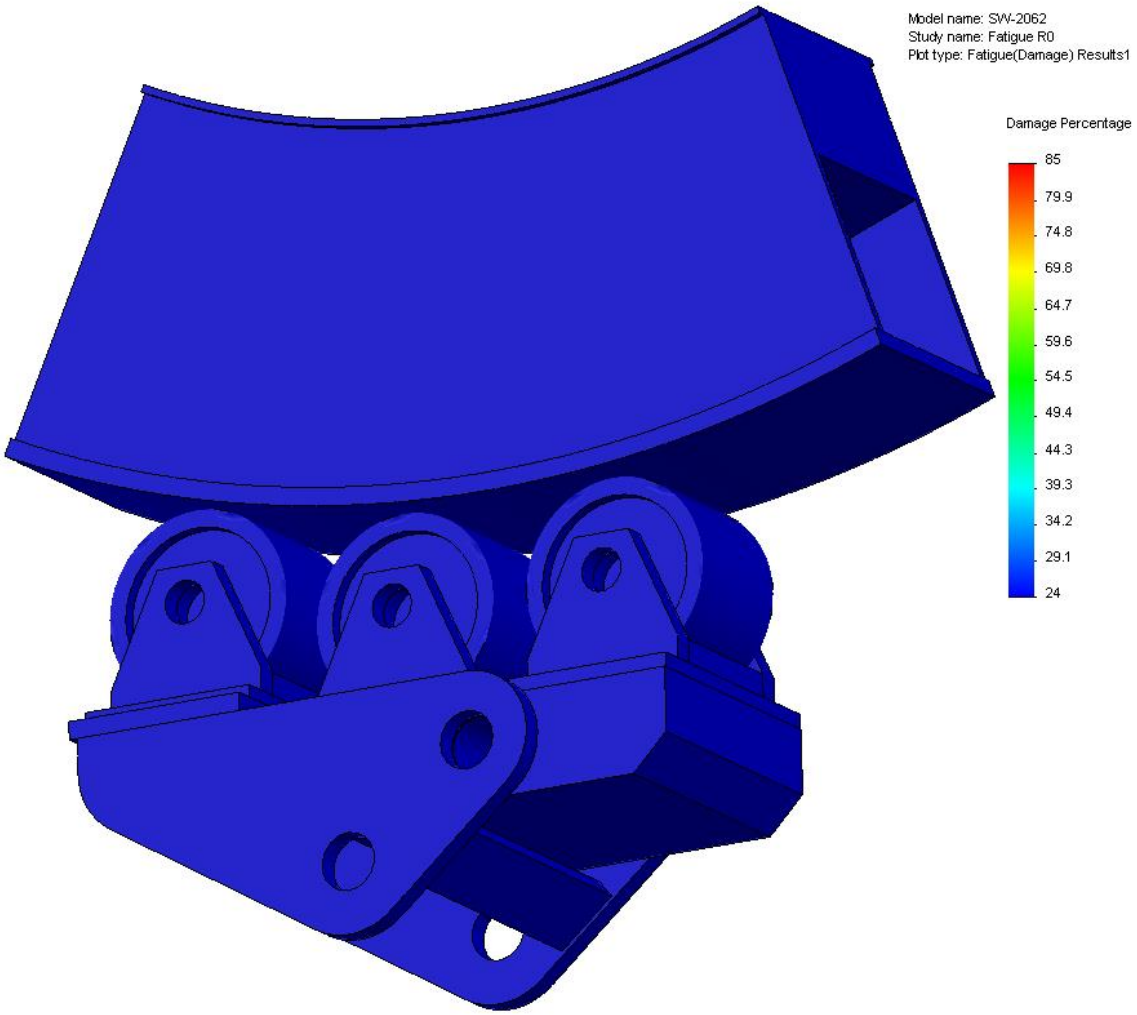
Static stress analysis for cylindrical rollers showed peak value in the spot area on one of the rollers. When we disregard this computational peak value, the maximal Von Misses stress value should be about **105 N/mm^2** .

Maximal value of contact pressure is also computational peak value. When we disregard this computational peak value maximal value for contact pressure would be **151 N/mm^2.**

All following analysis including fatigue analysis for cylindrical rollers will be performed by using real stress value.

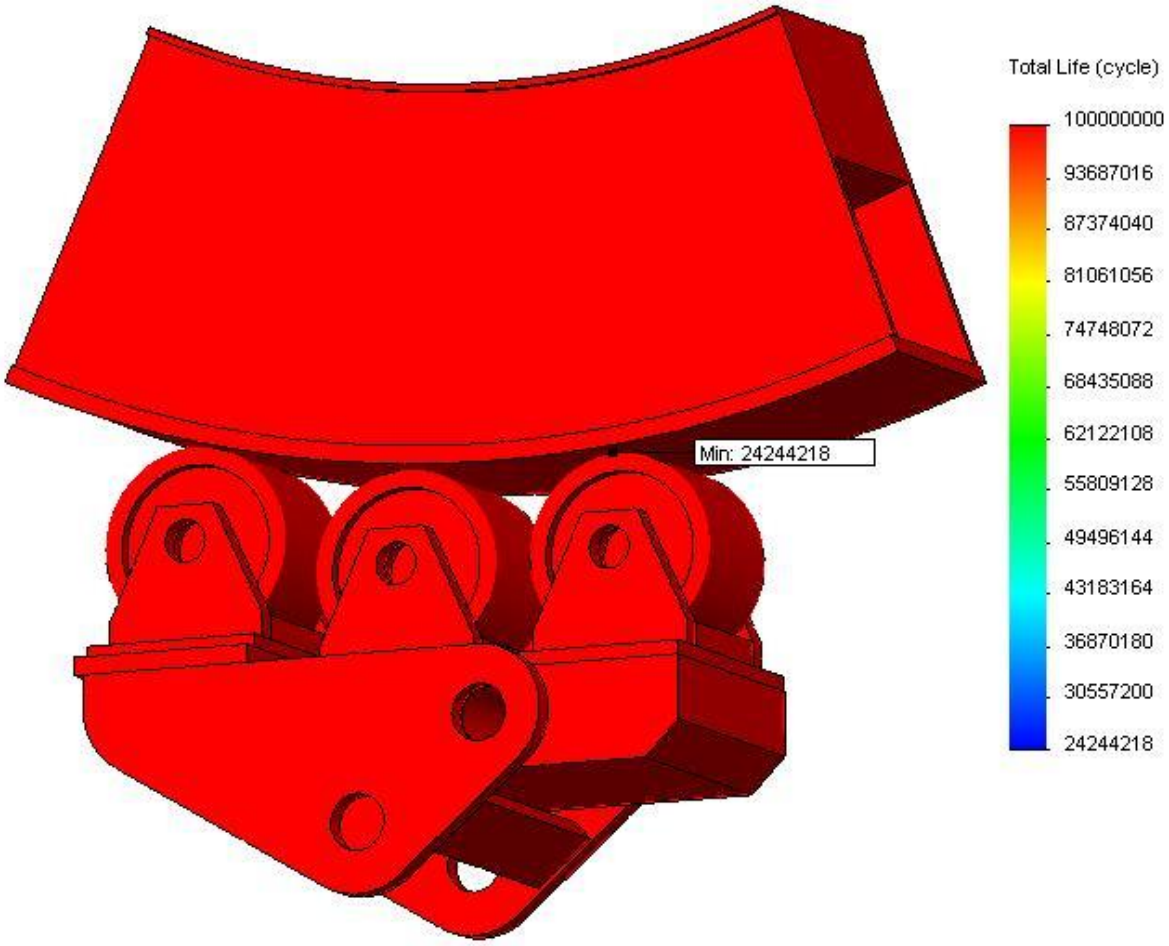
4. FATIGUE ANALYSIS FOR CYLINDRICAL ROLLERS

Fatigue analysis was performed taking in consideration real stress and contact pressure values. Computational peak values have been disregarded in static analysis.



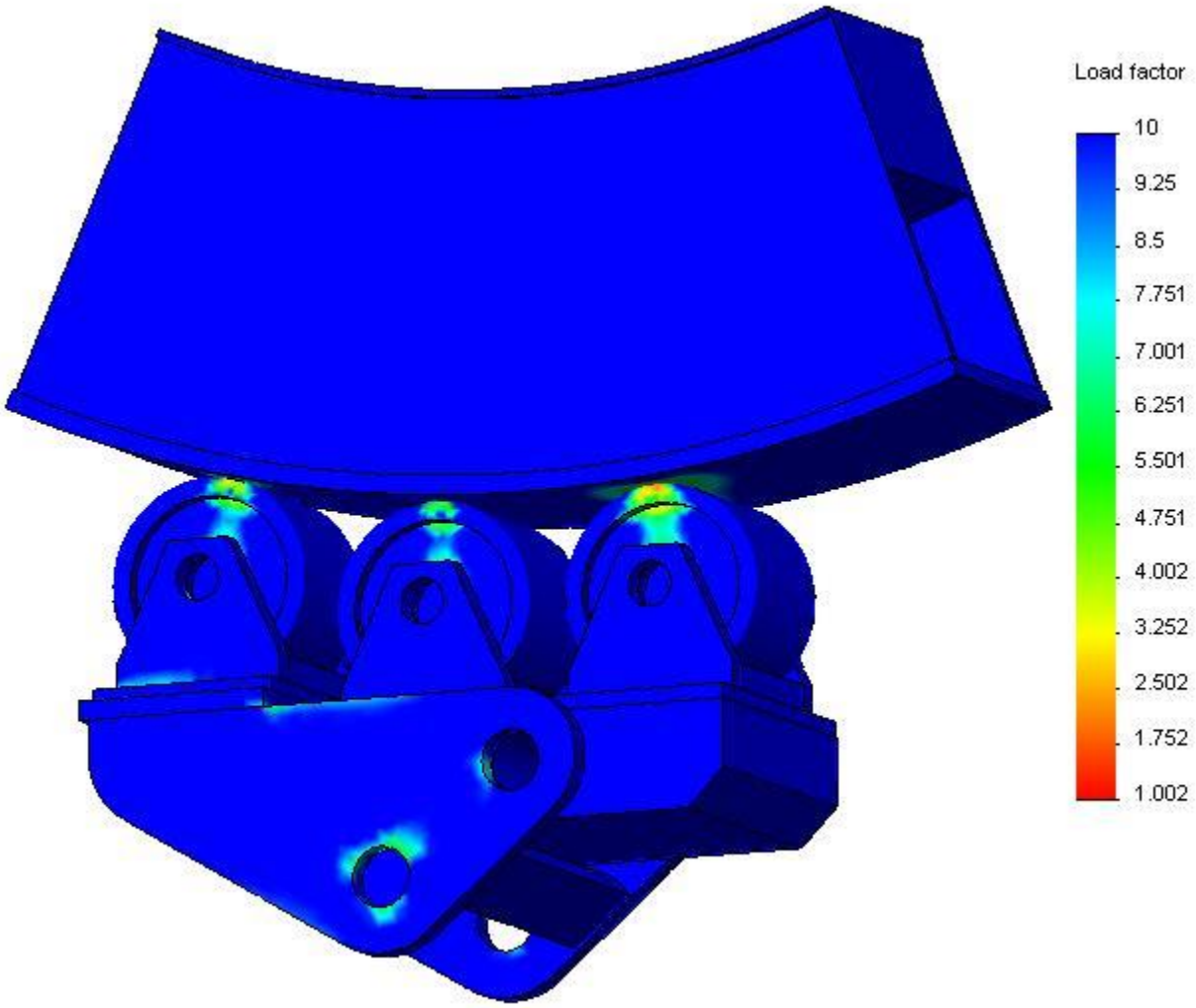
Fatigue - Damage

85 % of life for the right roller area is consumed after 24000000 cycles.



Fatigue – Total Life

Fatigue will occur after 24244218 cycles, at the corner of the right most roller. This is very close to the defined fatigue requirement but this is satisfactory results.



Fatigue-Load Factor

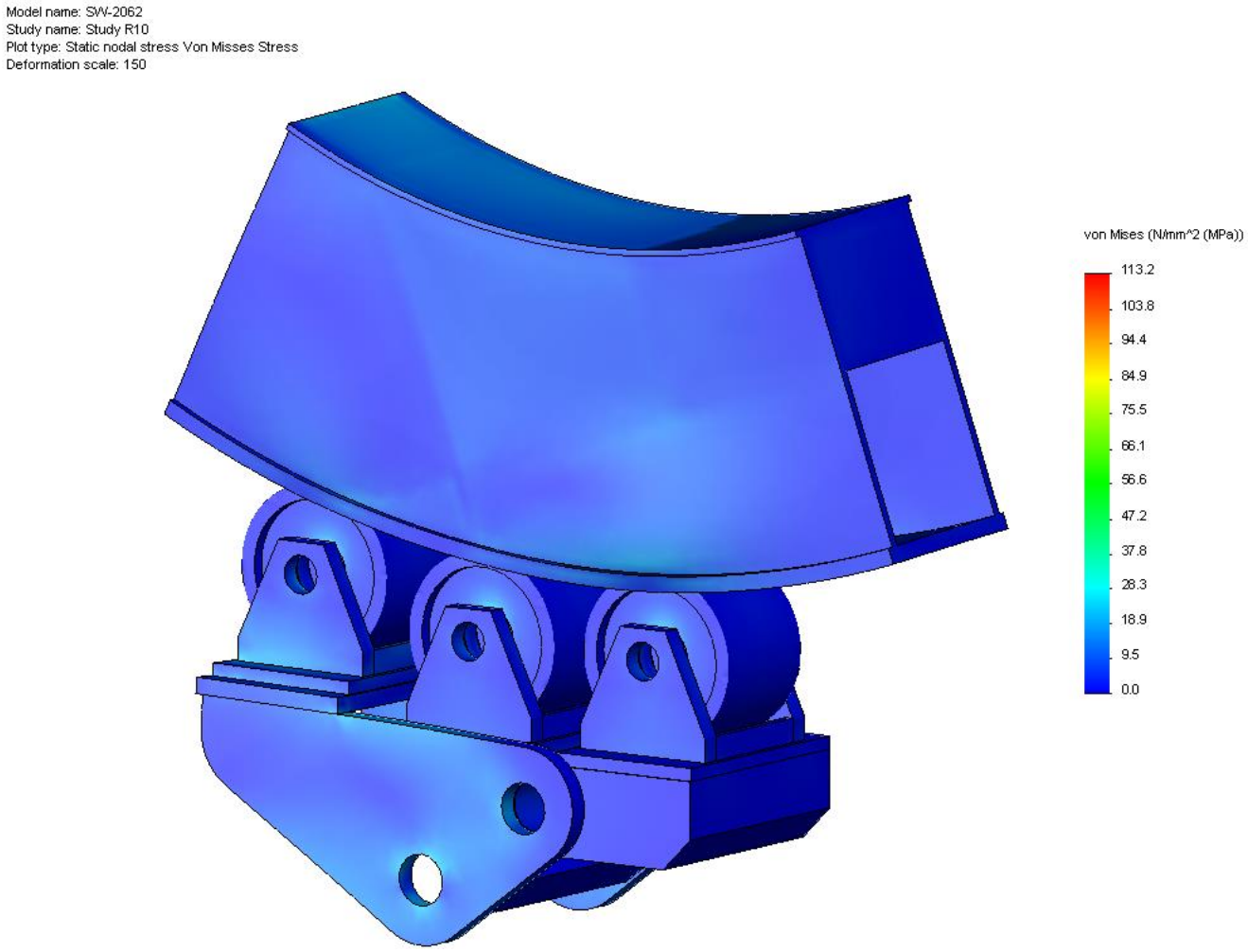
If we multiply current loads with load factor, fatigue would occur for our structure.

The design of ring and rollers subassembly will successfully achieve design goal of 15 years in operation.

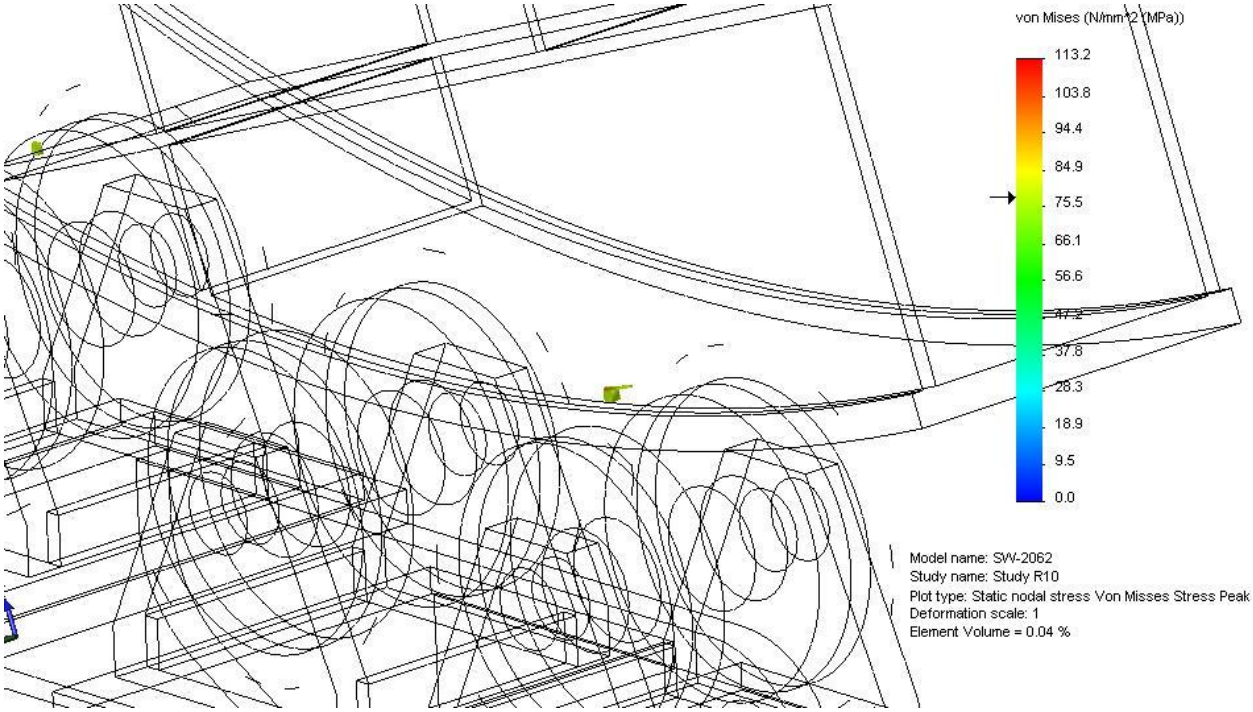
5. STRESS AND FATIGUE ANALYSIS WITH ROLLERS OPTIMISATION

The most appropriate way of eliminating before mentioned stress peak is changing the shape of the rollers, actually choosing the barrel shaped rollers. The shape of the rollers can be controlled by changing an additional parameter known as camber radius. For the purpose of optimization we will choose four specific values for camber radius. Considered values will be: 10m, 20m, 40m and 60m radius.

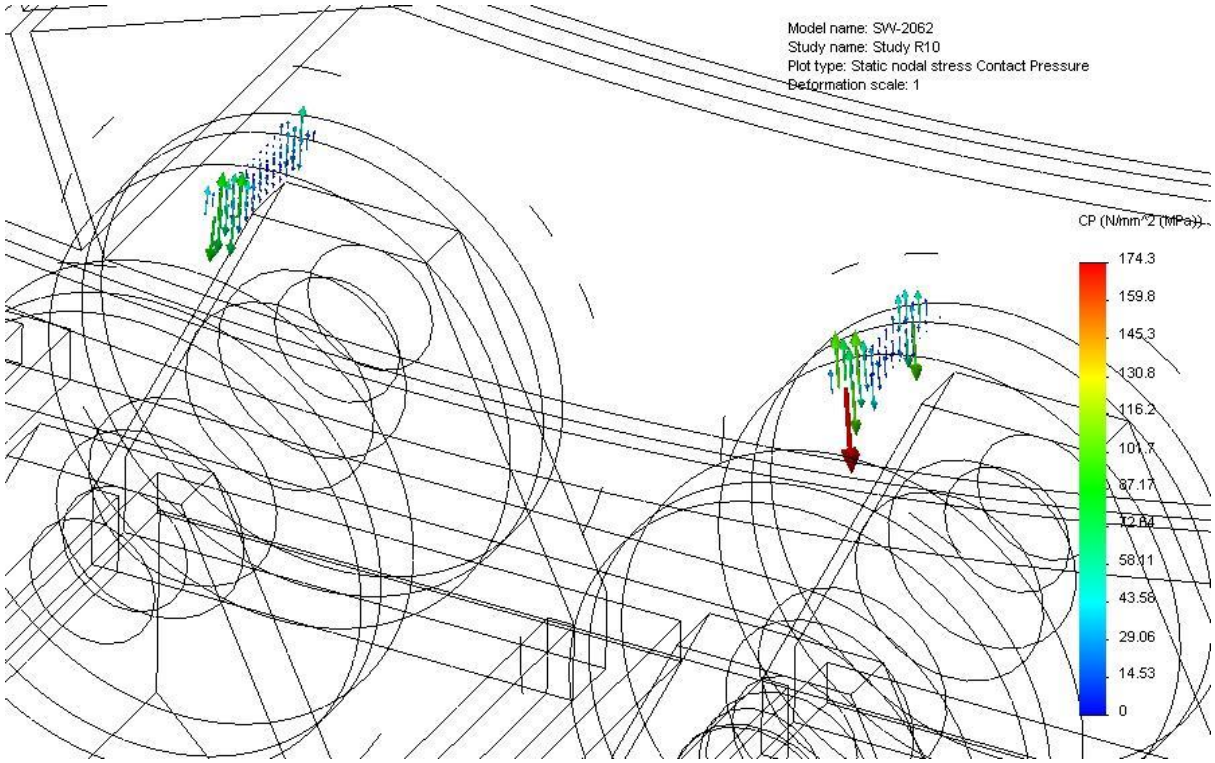
5.1. Analysis for the rollers with 10m camber radius



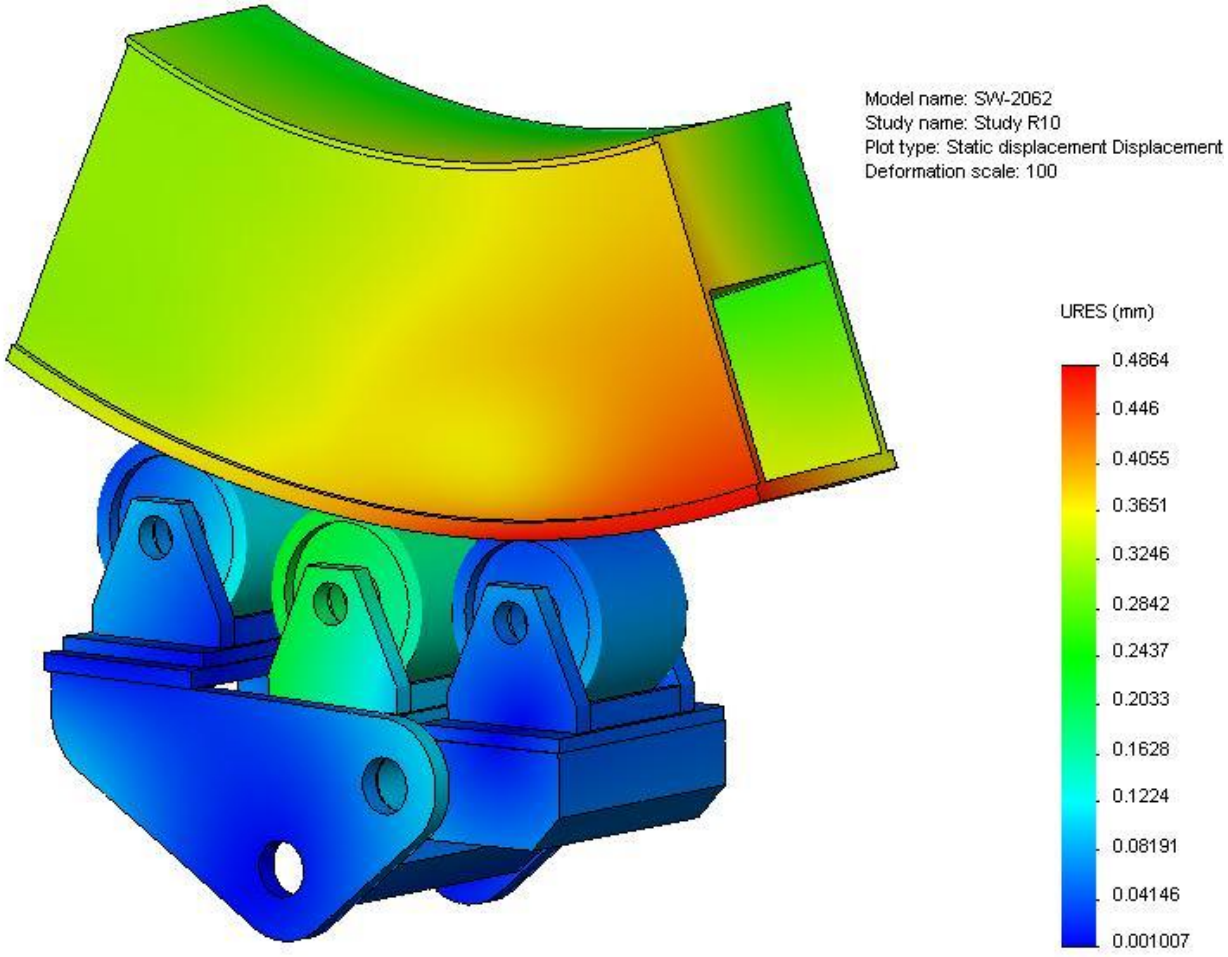
Von Misses Stress



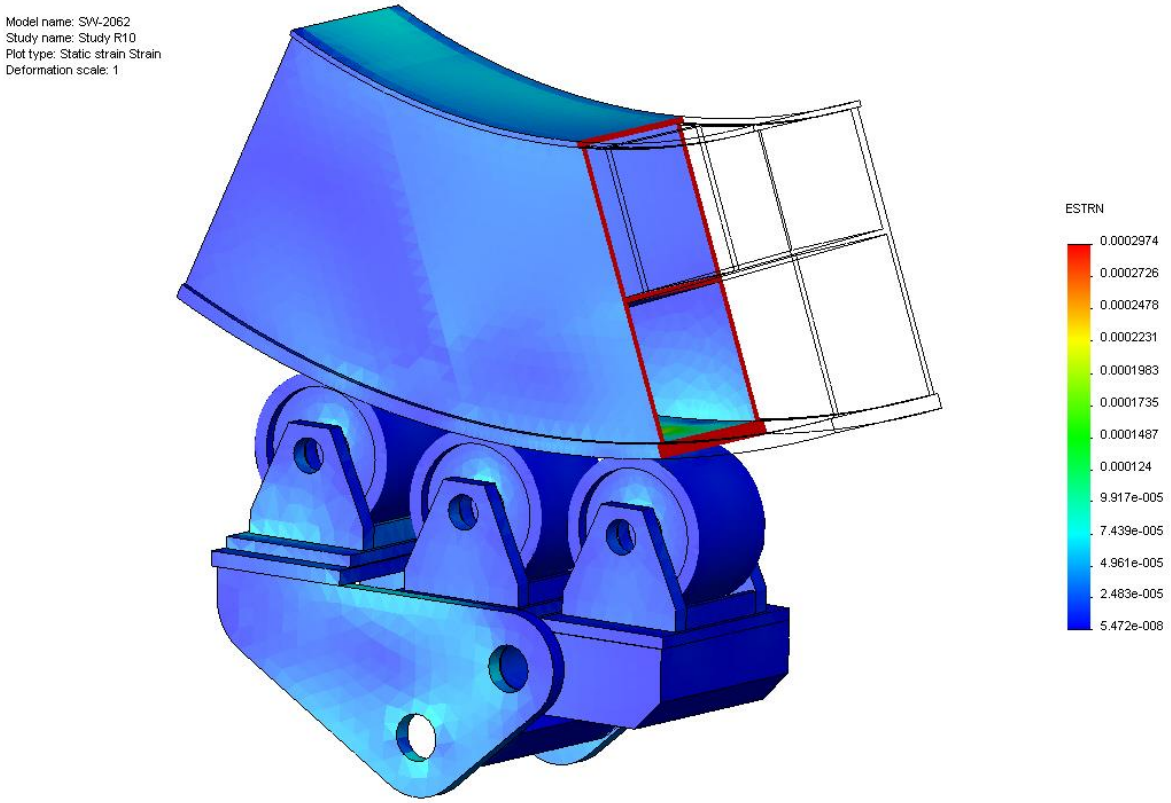
Von Misses Stress Peak



Contact Pressure



Displacement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Study name: Study R10
Plot type: Static strain Strain
Deformation scale: 1
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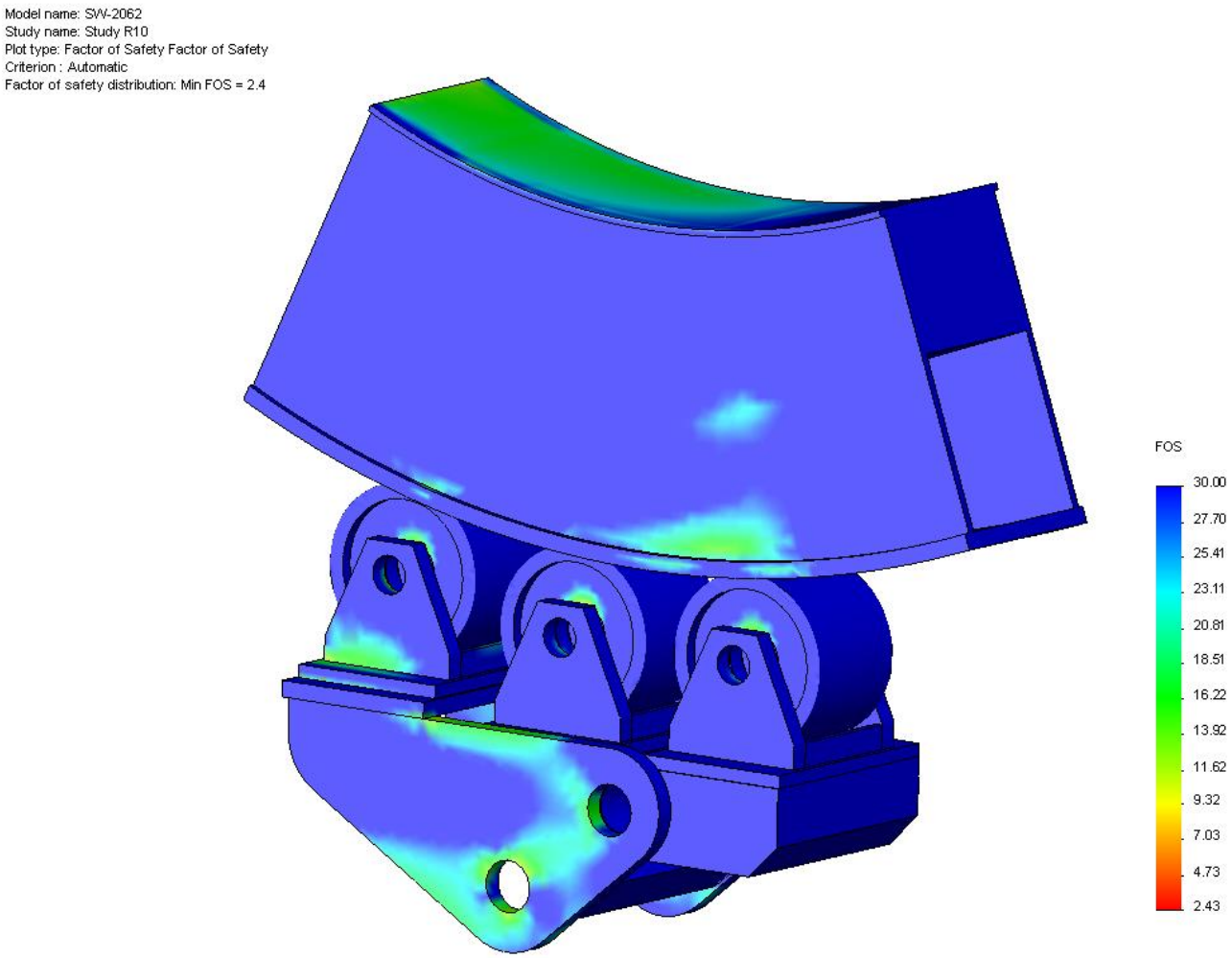
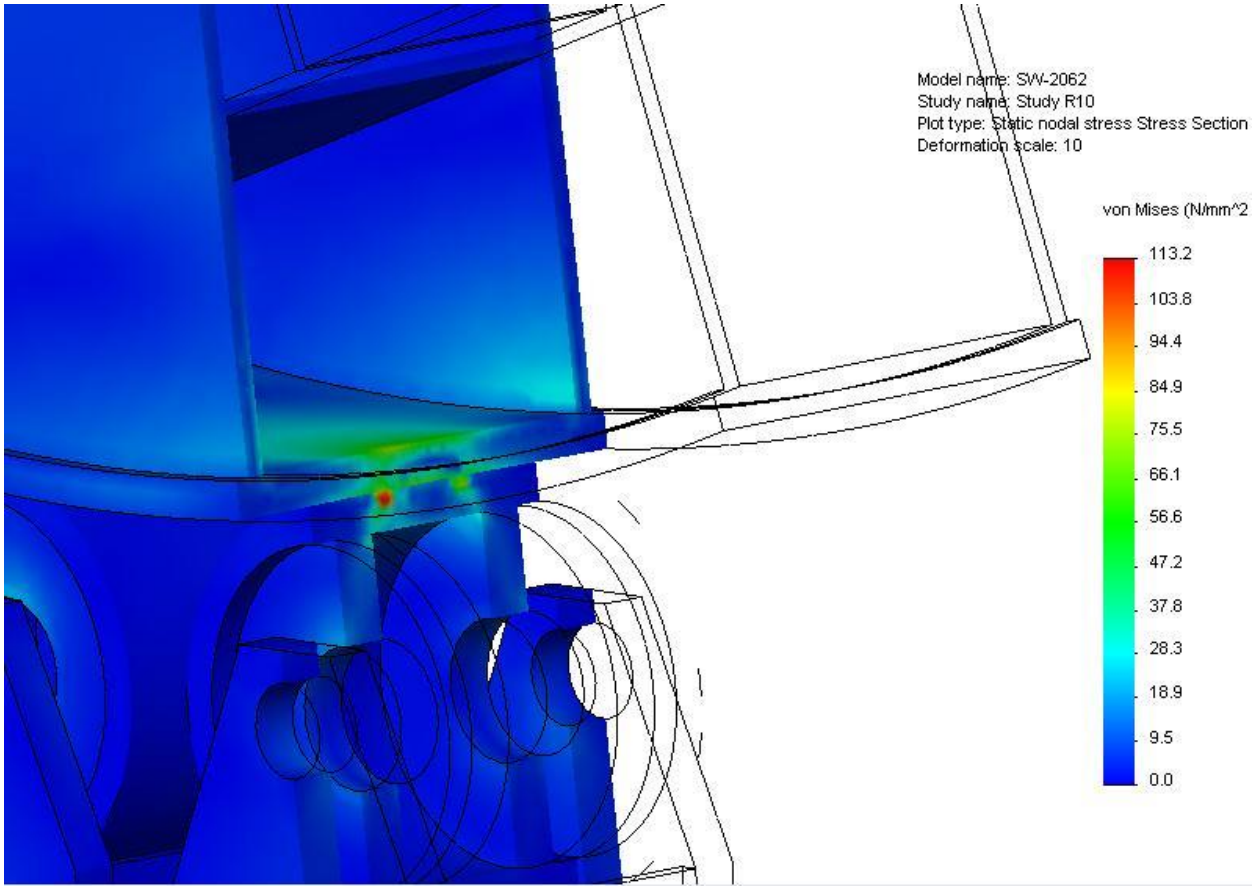
7.439e-005
4.961e-005
2.483e-005
5.472e-008

Strain



Factor of Safety

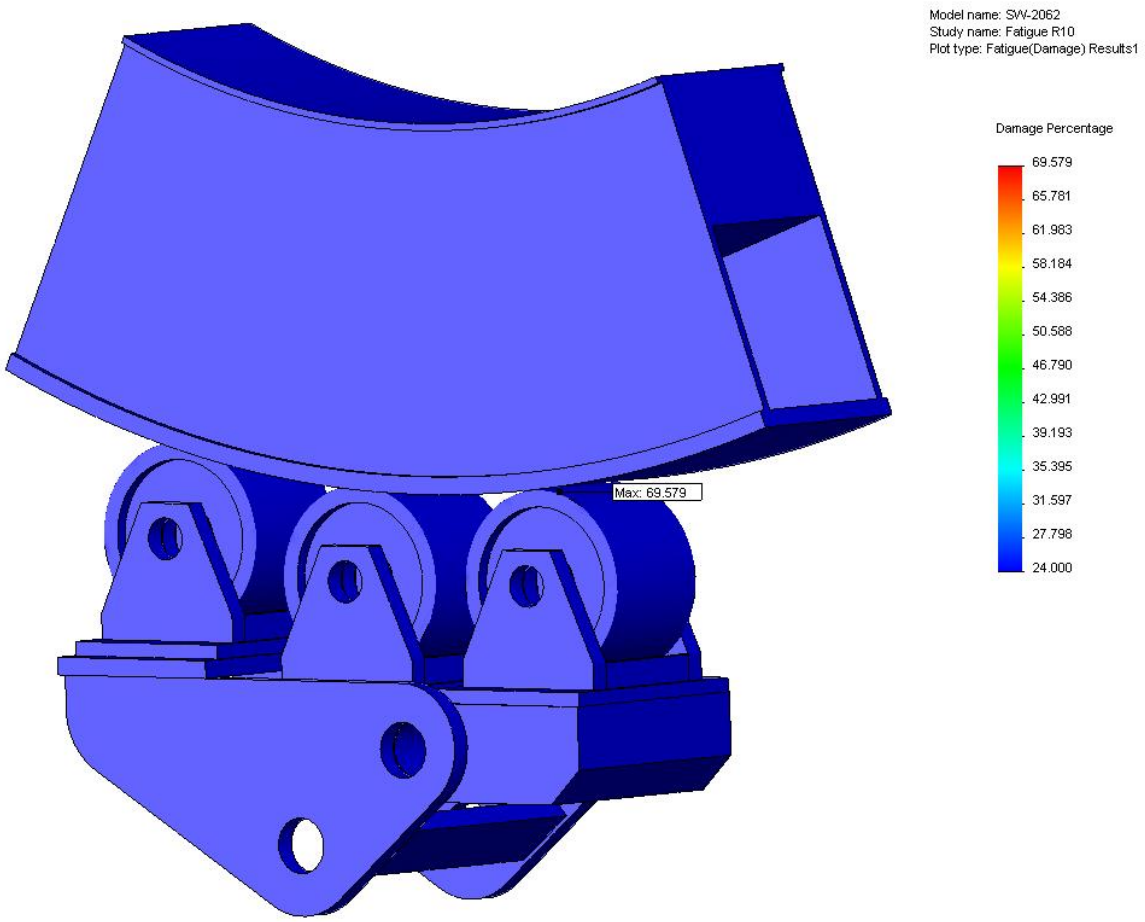


Von Misses Stress - Section

Static stress analysis for cylindrical rollers showed peak value in the spot area on one of the rollers. When we disregard this computational peak value, the maximal Von Misses stress value should be about **95 N/mm²** .

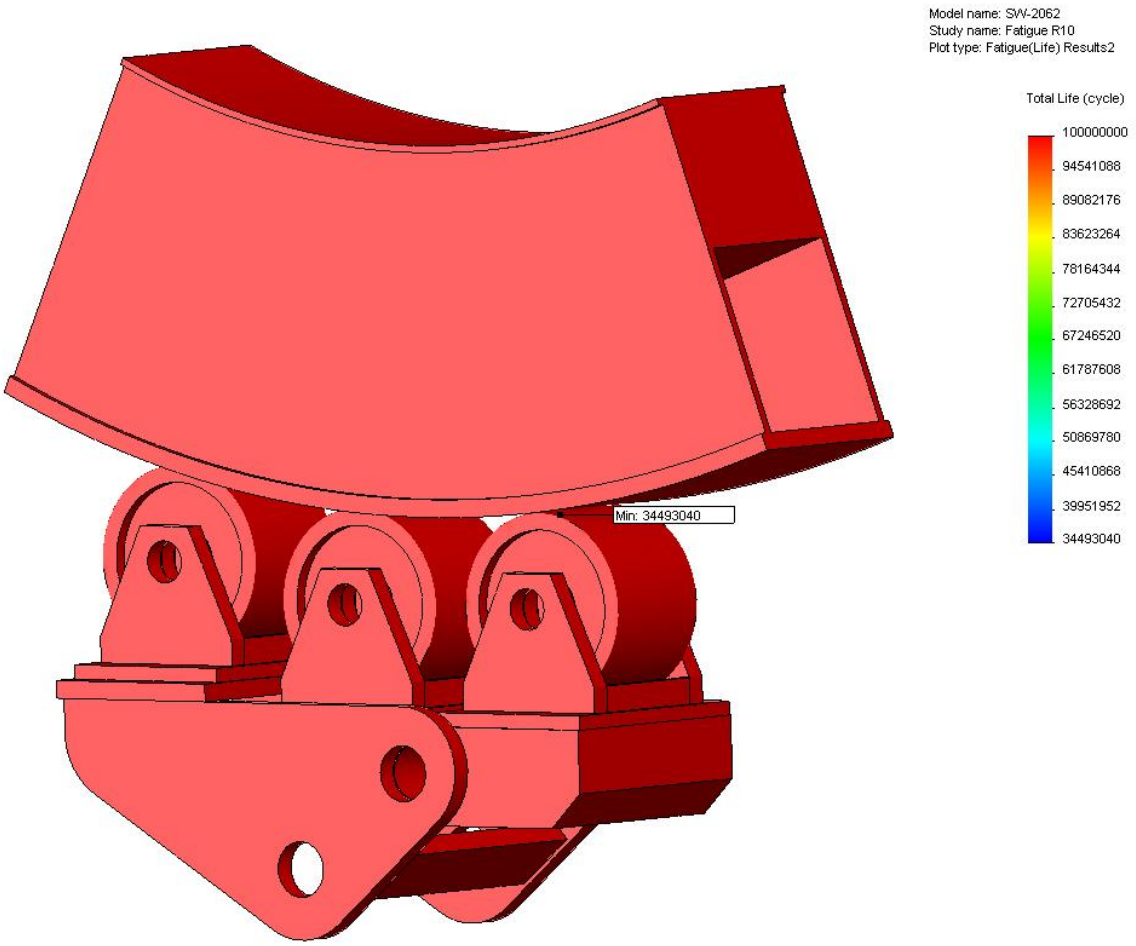
Maximal value of contact pressure is also computational peak value. When we disregard this computational peak value maximal value for contact pressure would be **146 N/mm².**

All following analysis including fatigue analysis for cylindrical rollers will be performed by using real stress value.



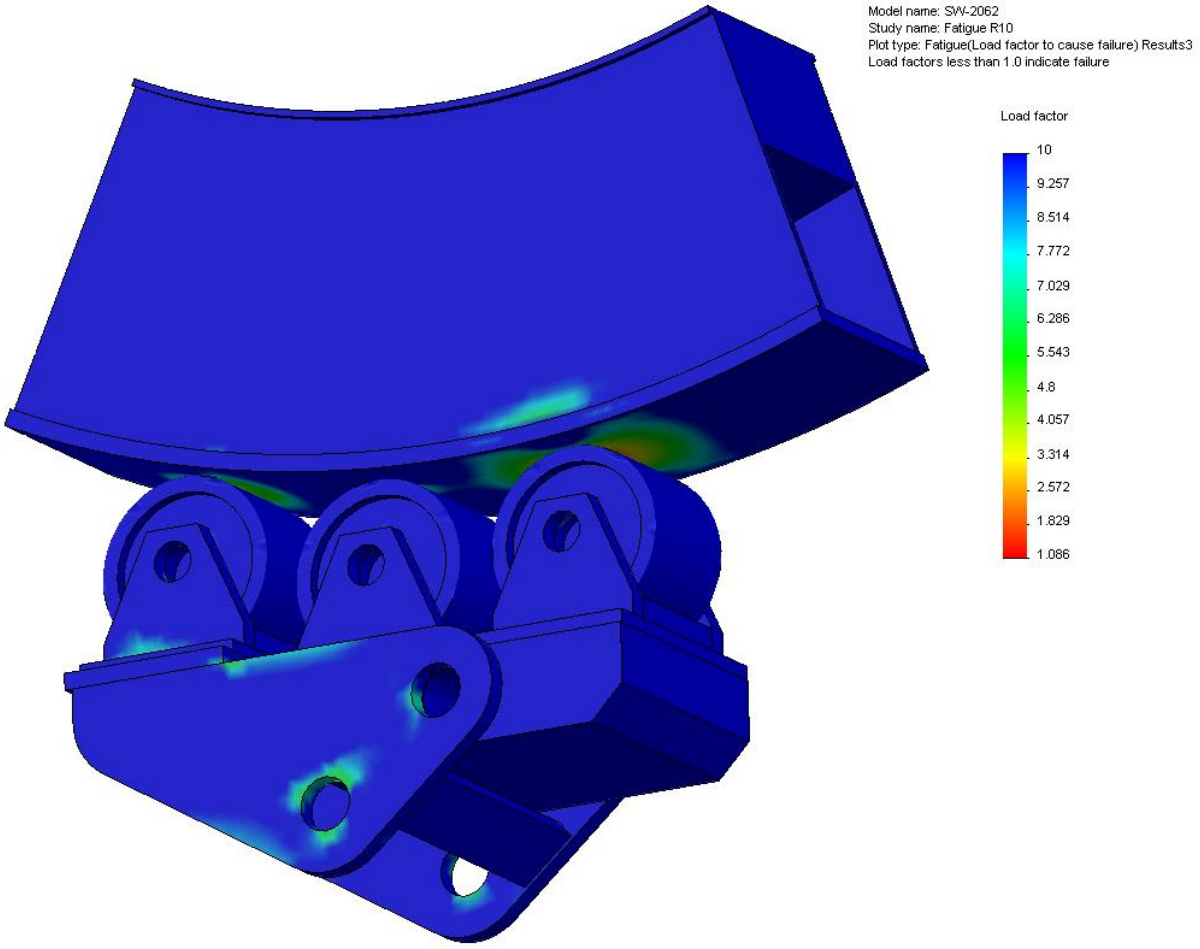
Fatigue - Damage

69.6 % % of life for the right roller area is consumed after 24000000 cycles. This is clearly small area and situation in reality is much better, when we disregard stress peaks.



Fatigue – Total Life Cycle

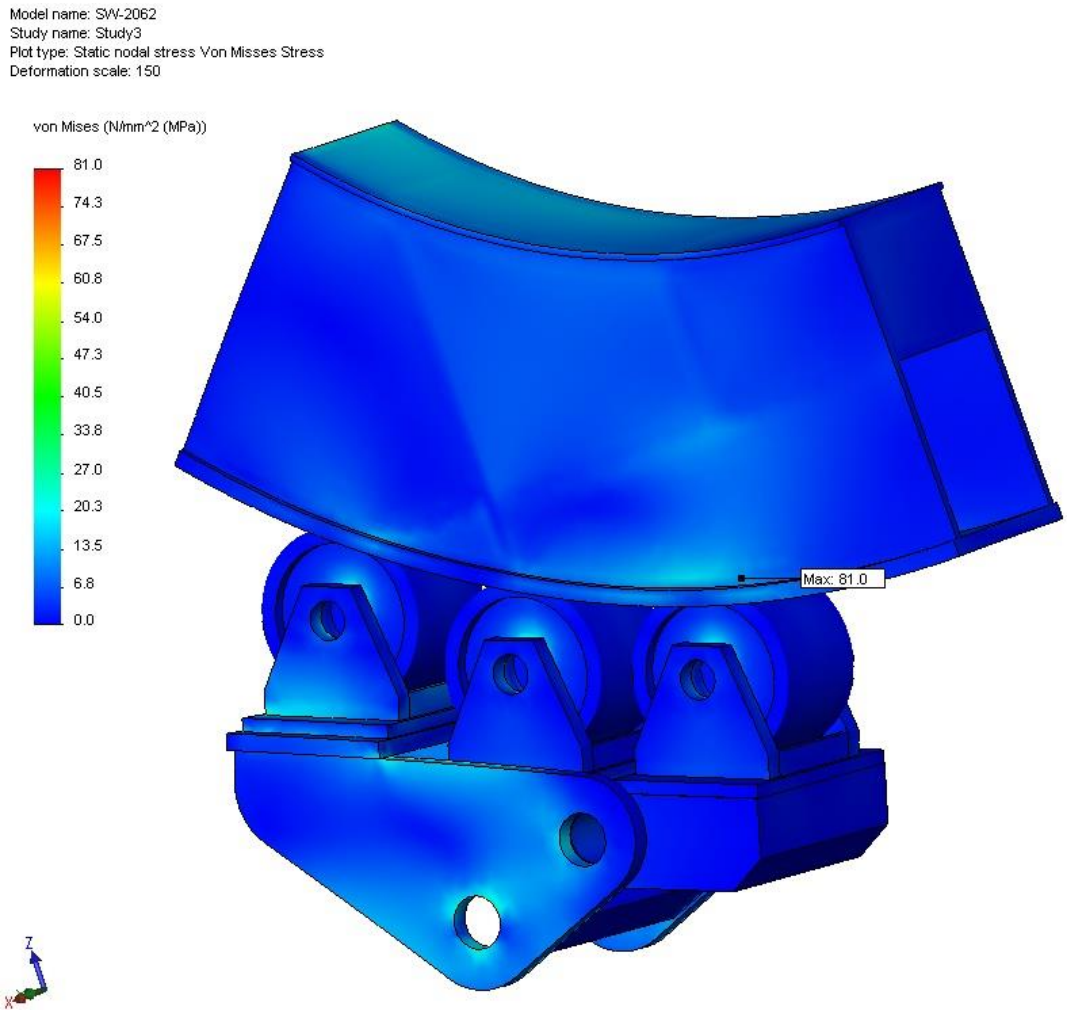
Fatigue will occur after 34493040 cycles, at the corner of the right most roller. In reality stress peak present in this area does not exist, so number of cycles is greater then mentioned.



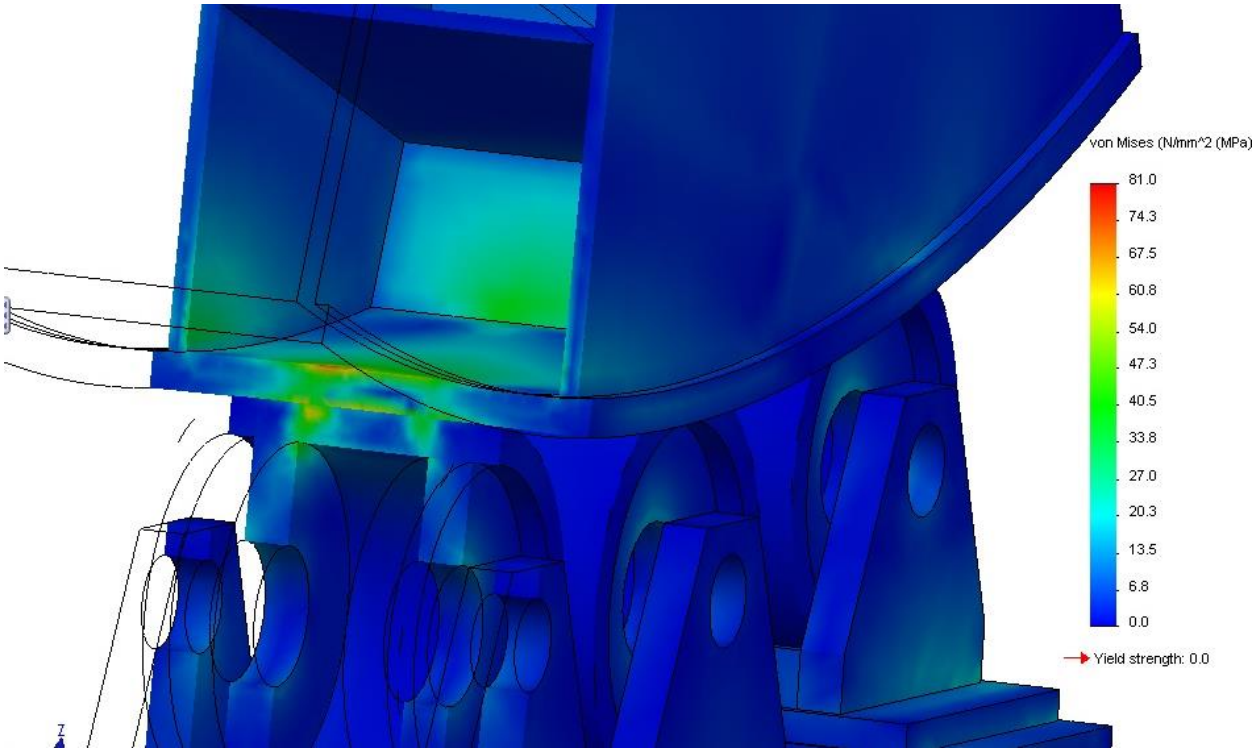
Fatigue - load factor

The design of ring and rollers subassembly will successfully achieve design goal of 15 years in operation.

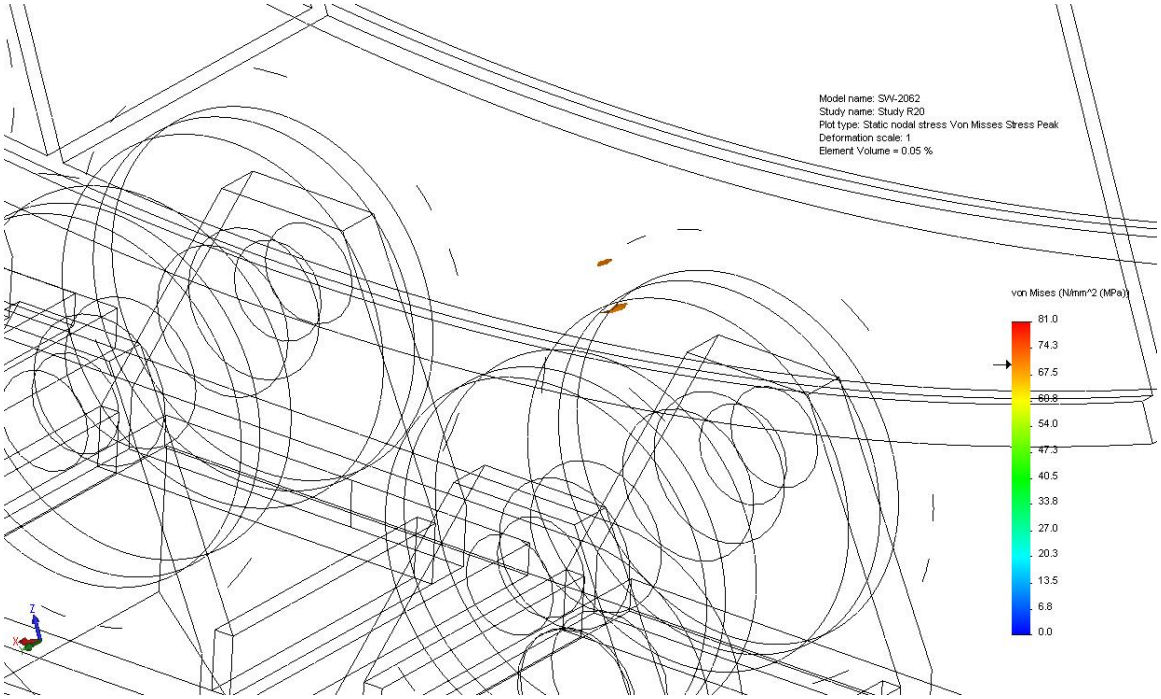
5.2. Analysis for the rollers with 20m camber radius



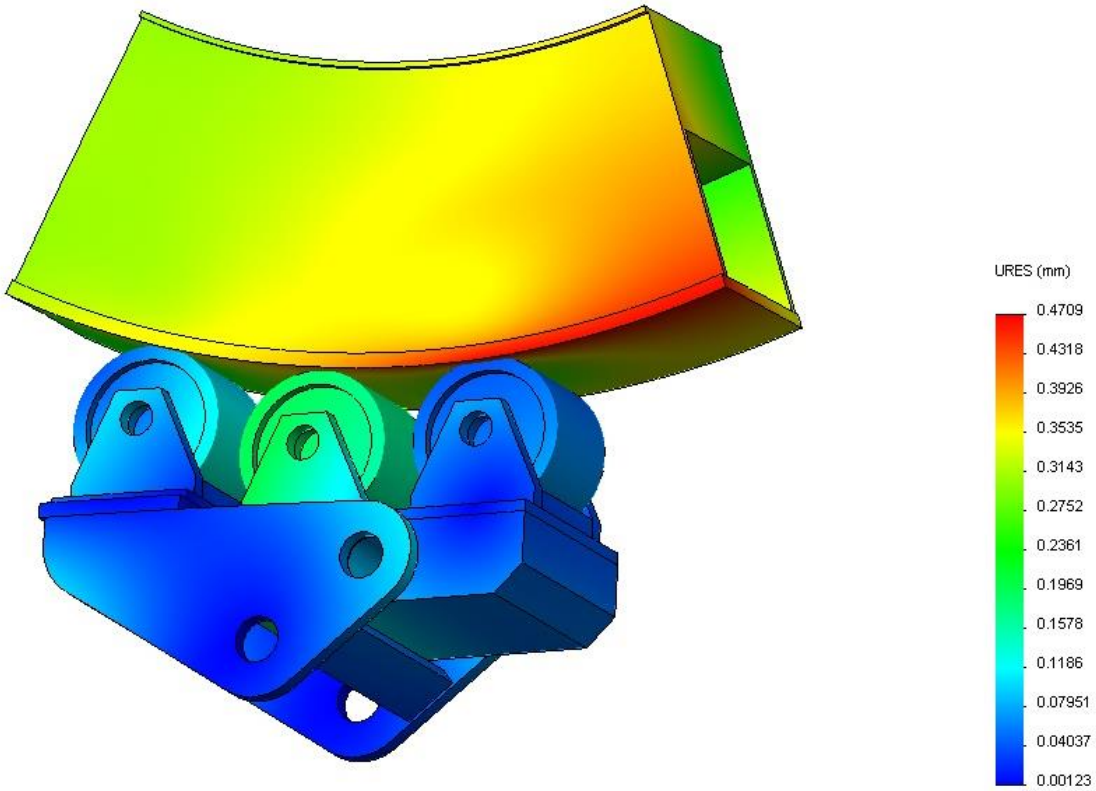
Von Misses Stress



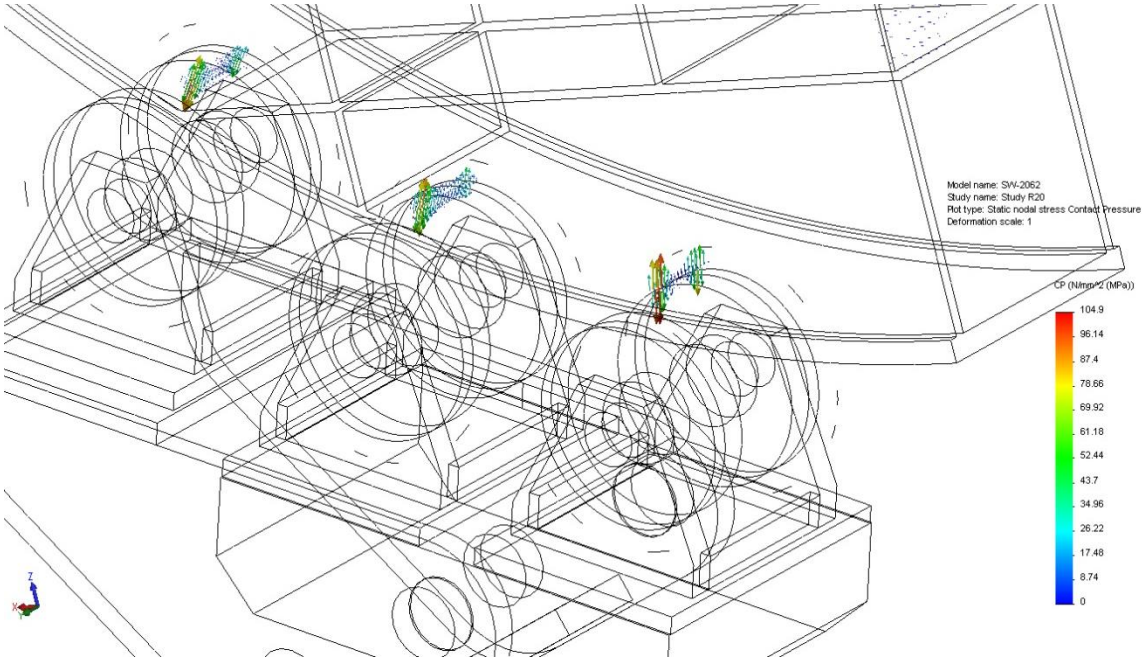
Von Misses Stress



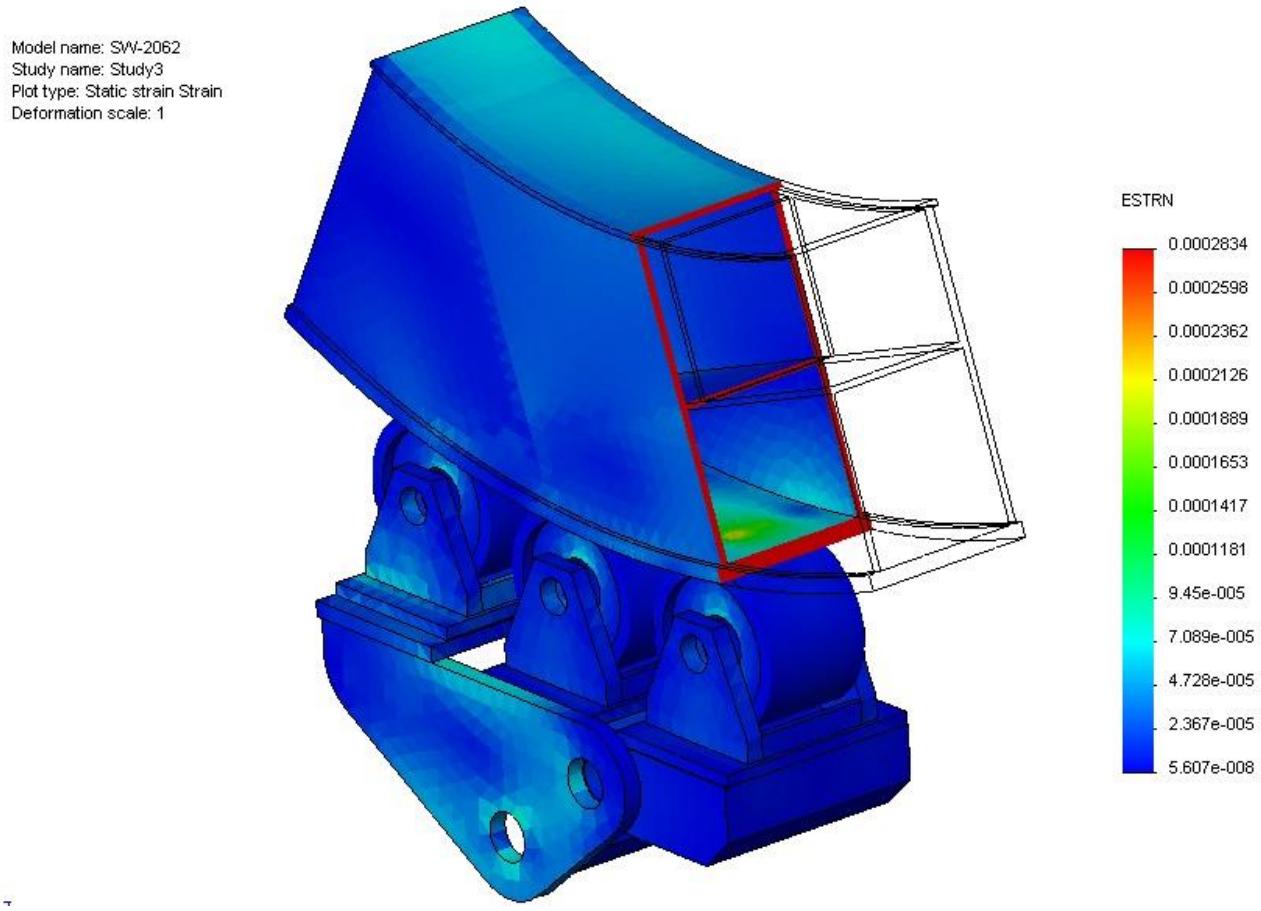
Von Misses Stress Peak



DIsplacement



Contact Pressure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Study name: Study3
Plot type: Static strain Strain
Deformation scale: 1
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0.0001181
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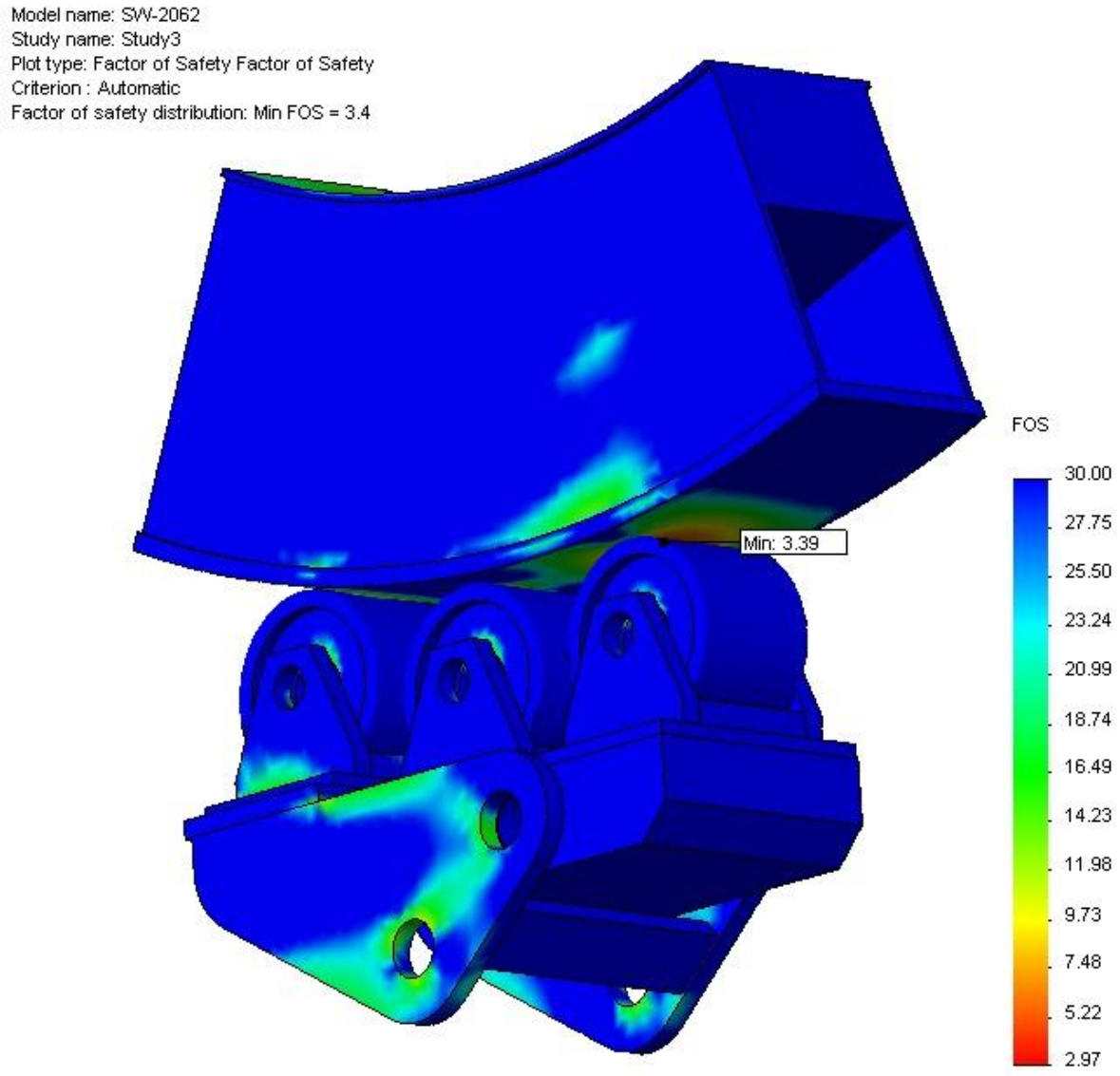
7.089e-005
4.728e-005
2.367e-005
5.607e-008

Strain

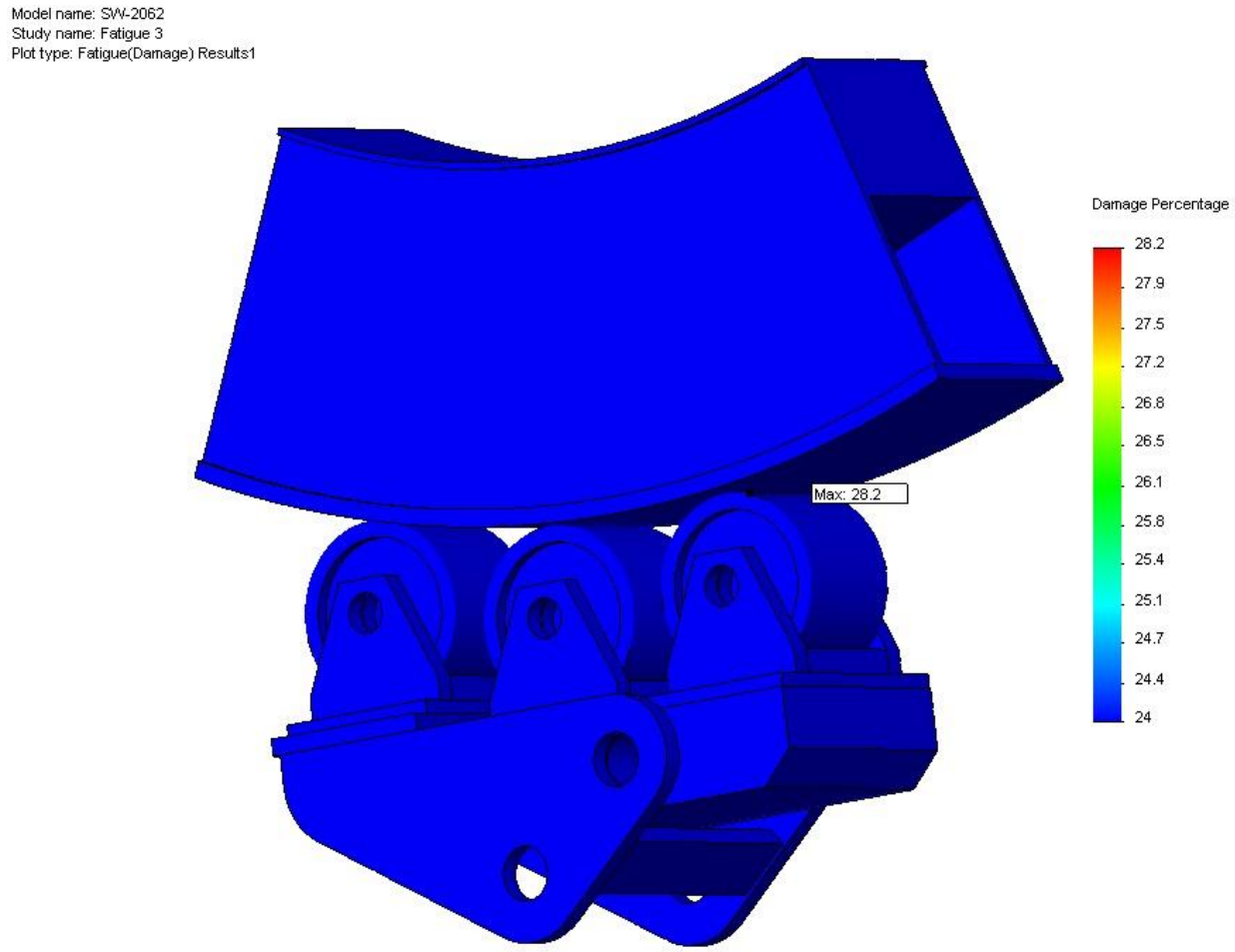


Factor of Safety

Static stress analysis for cylindrical rollers showed peak value in the spot area on one of the rollers. When we disregard this computational peak value, the maximal Von Misses stress value should be about **75 N/mm^2** .

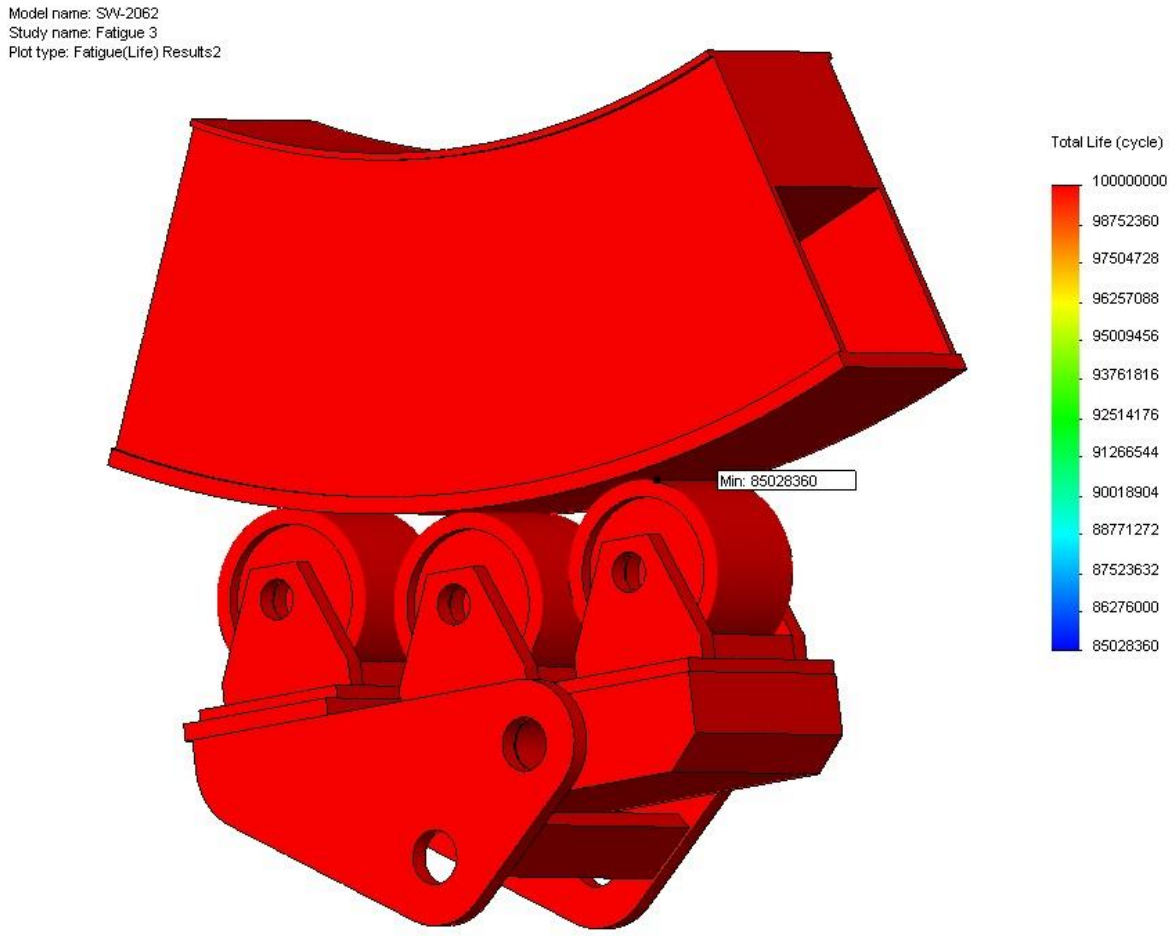
Maximal value of contact pressure is also computational peak value. When we disregard this computational peak value maximal value for contact pressure would be **97 N/mm^2.**

All following analysis including fatigue analysis for cylindrical rollers will be performed by using real stress value.



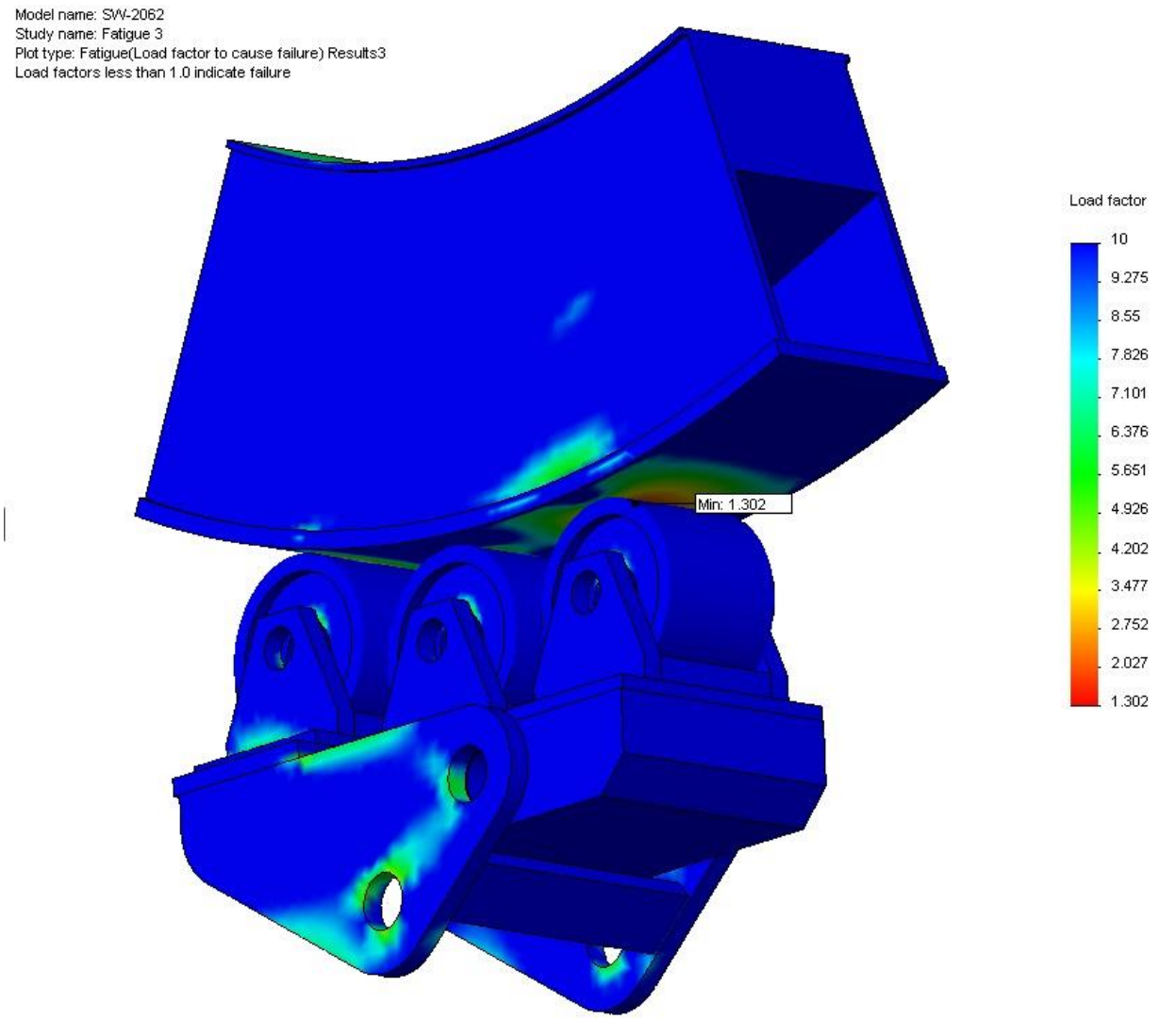
Fatigue – Damage

28 % of life for the right roller area is consumed after 24000000 cycles. This is clearly small area and situation in reality is much better, when we disregard stress peaks.



Fatigue – Total life cycle

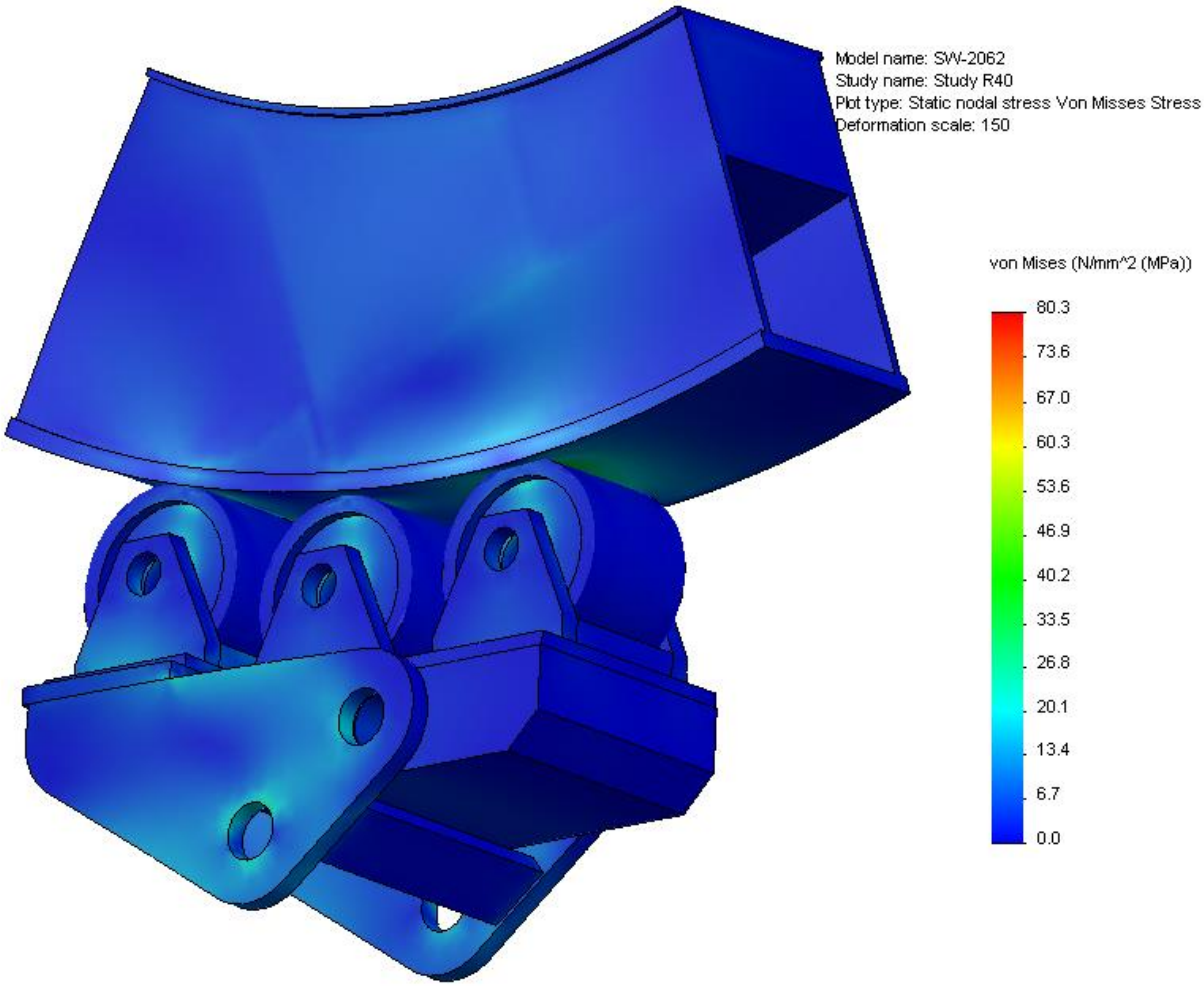
Fatigue will occur after 85028360 cycles, at the corner of the right most roller. In reality stress peak present in this area does not exist, so number of cycles is greater then mentioned.



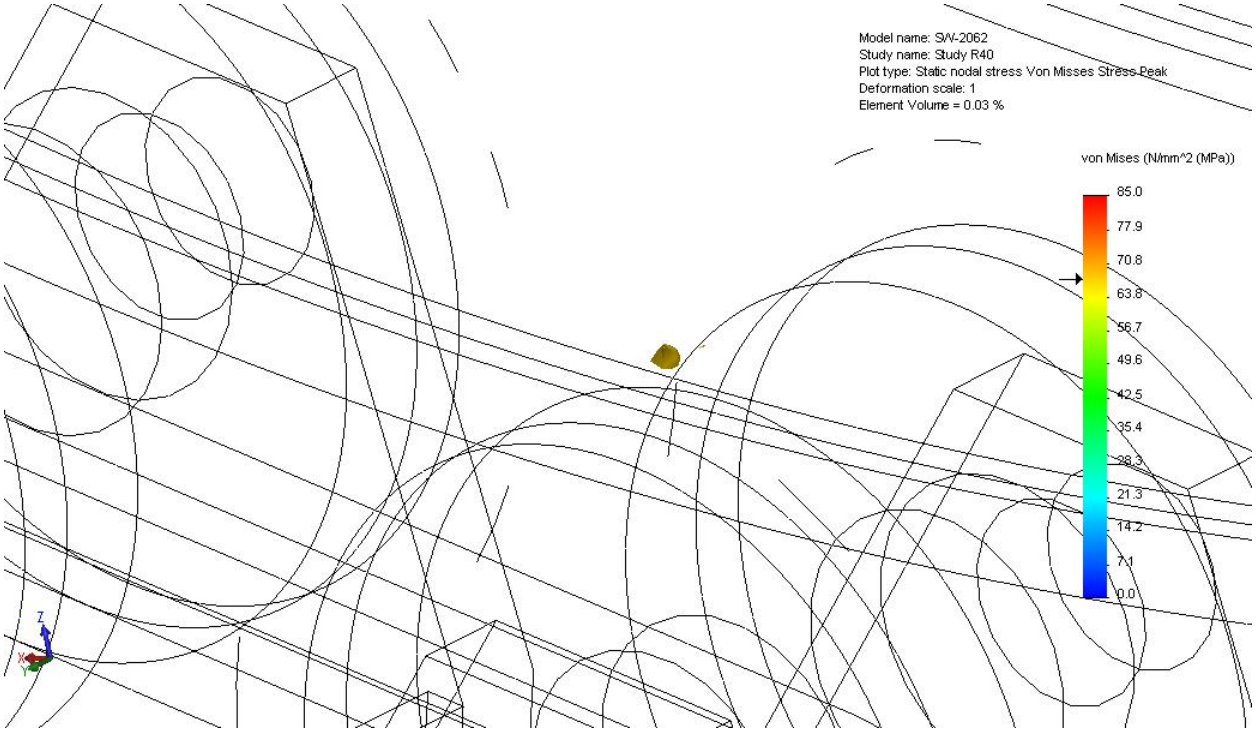
Fatigue – Load factor

The design of ring and rollers subassembly will successfully achieve design goal of 15 years in operation.

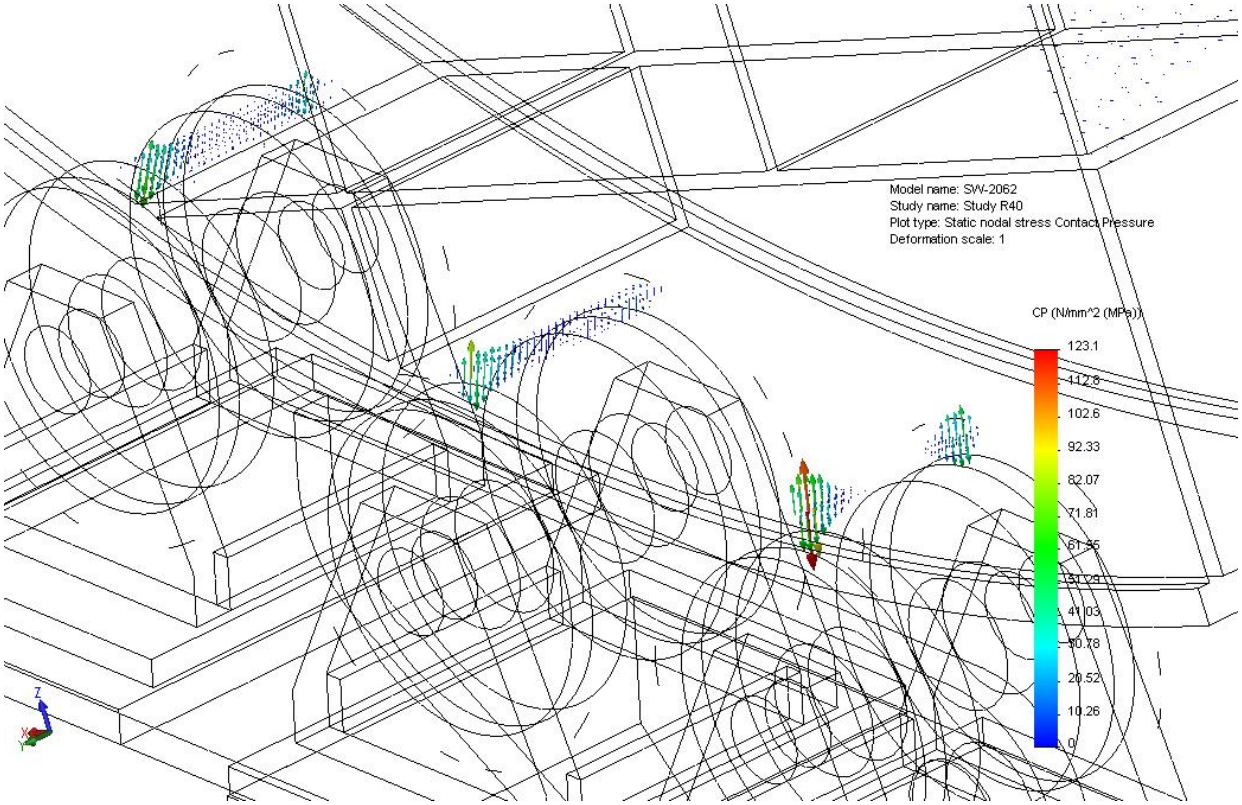
5.3. Analysis for the rollers with 40m camber radius



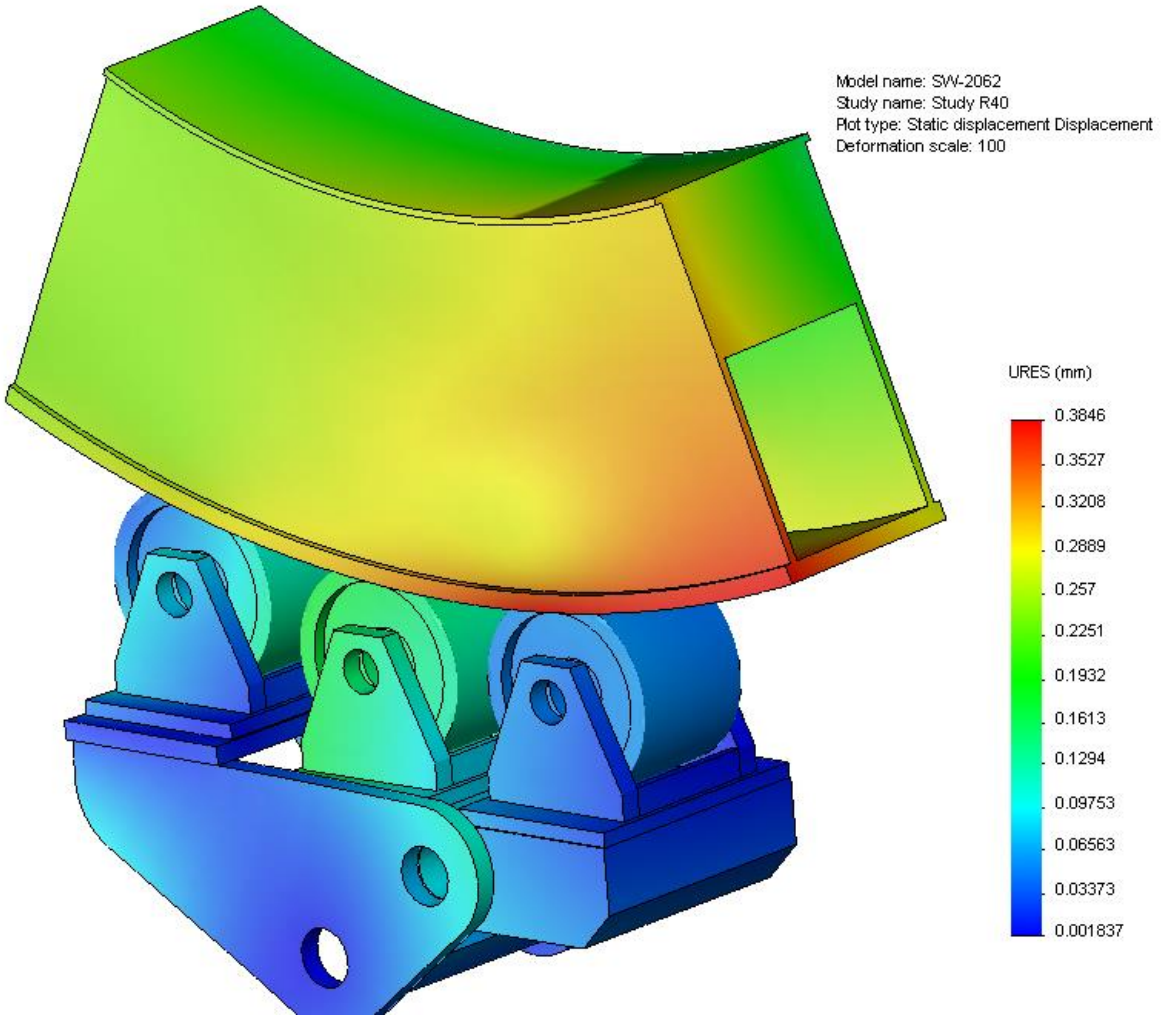
Von Misses Stress



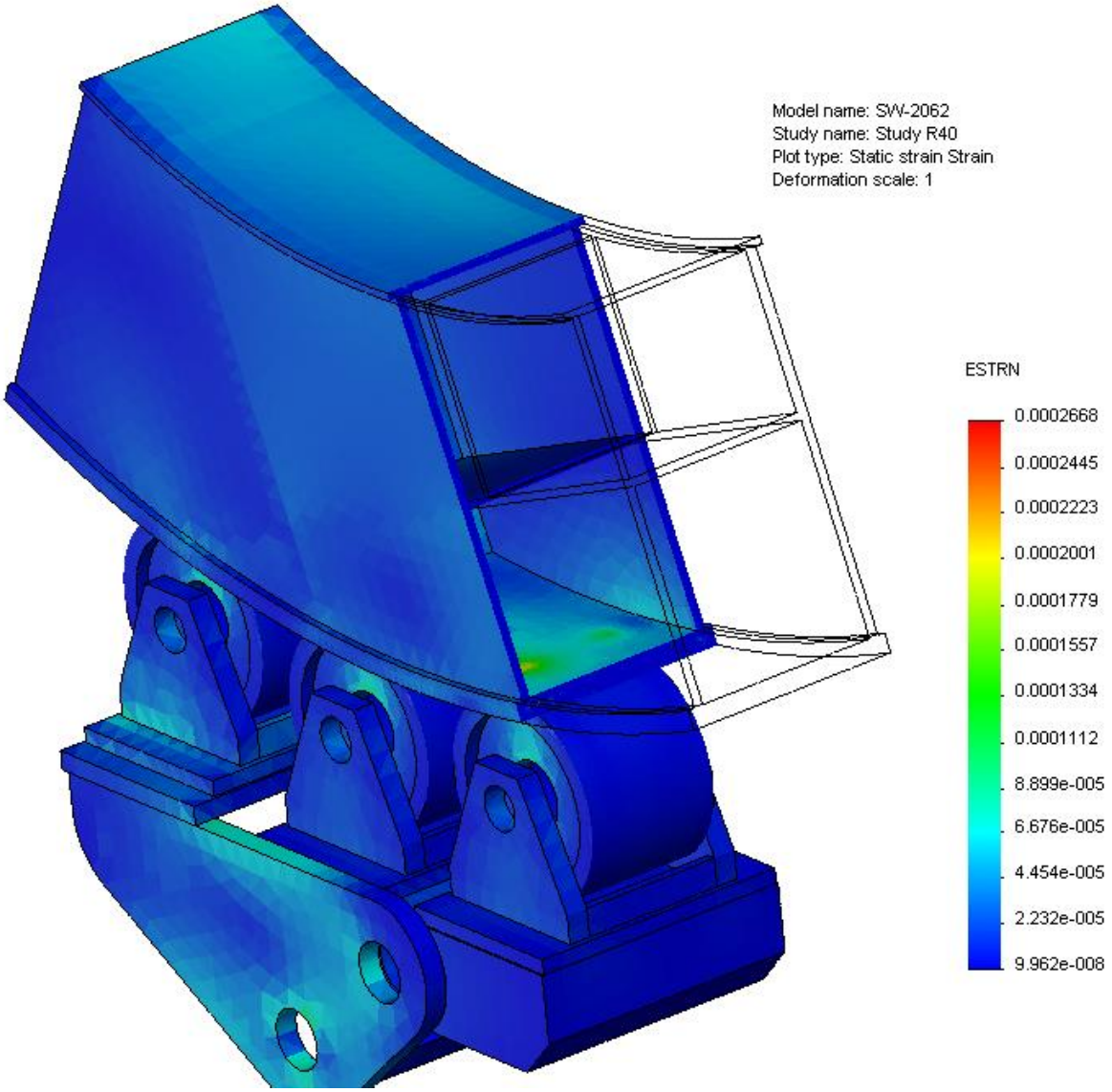
Von Misses Stress Peak



Contact Pressure



Displacement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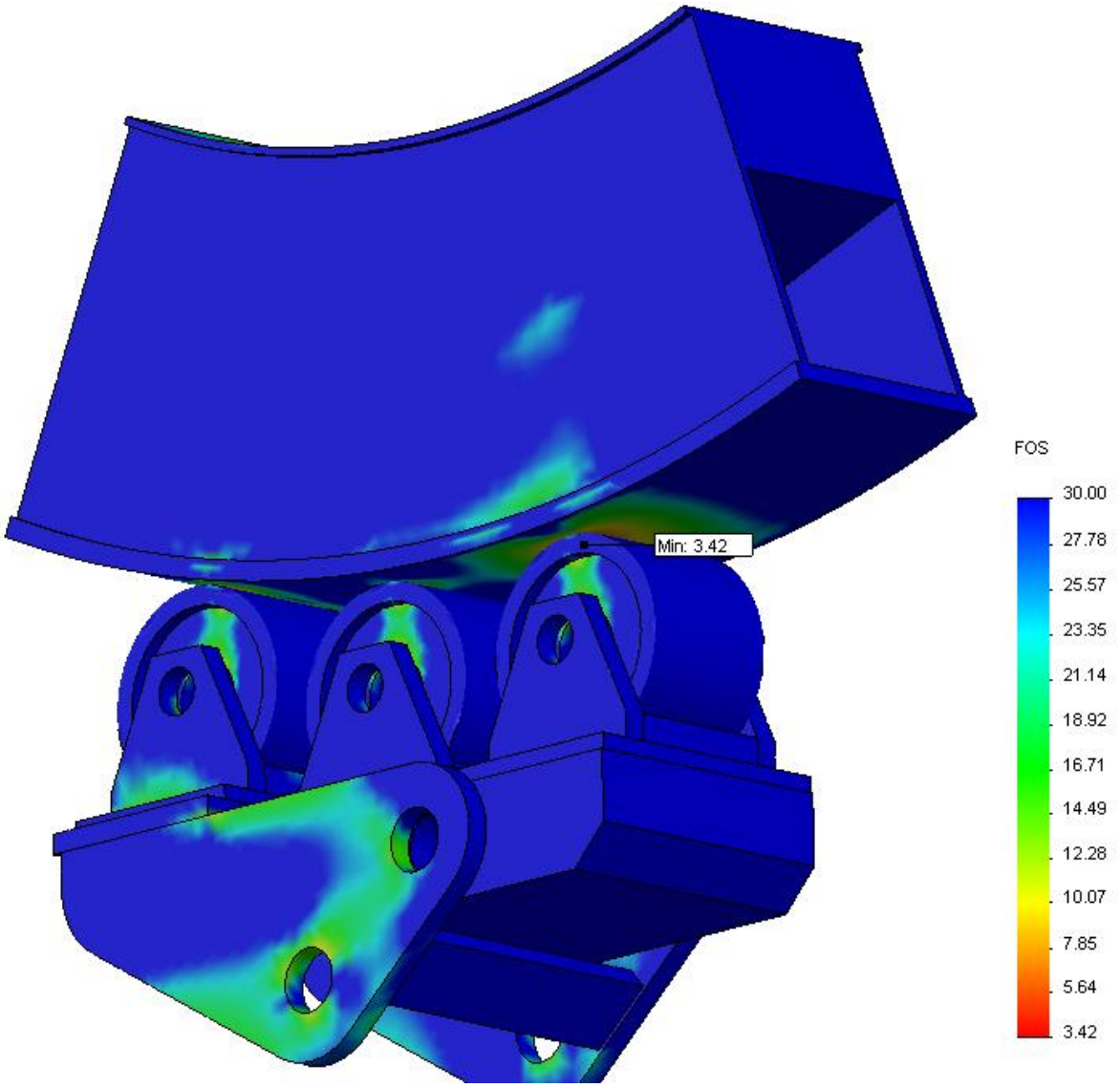
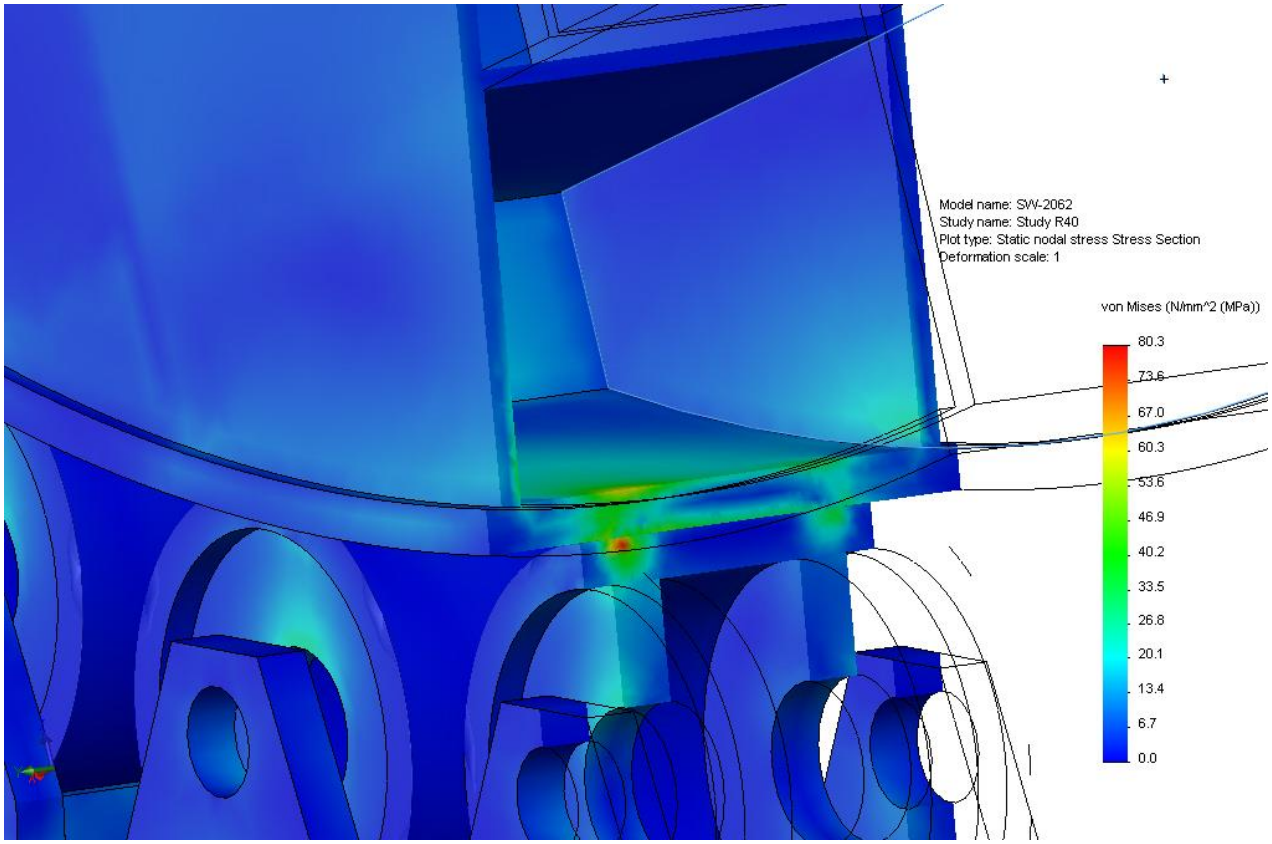
Strain



Factor of Safety

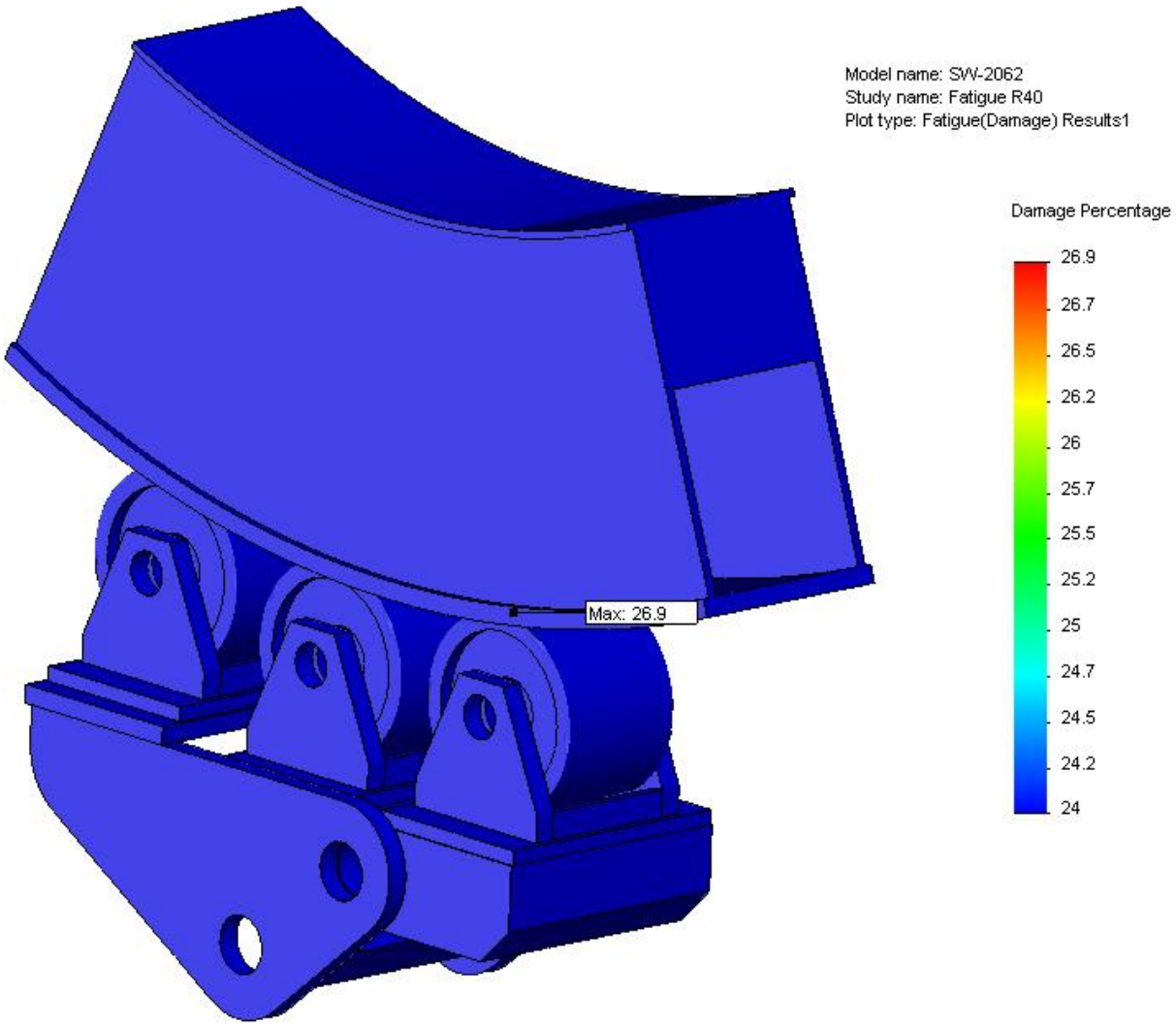


Stress Section

Static stress analysis for cylindrical rollers showed peak value in the spot area on one of the rollers. When we disregard this computational peak value, the maximal Von Misses stress value should be about **74 N/mm^2** .

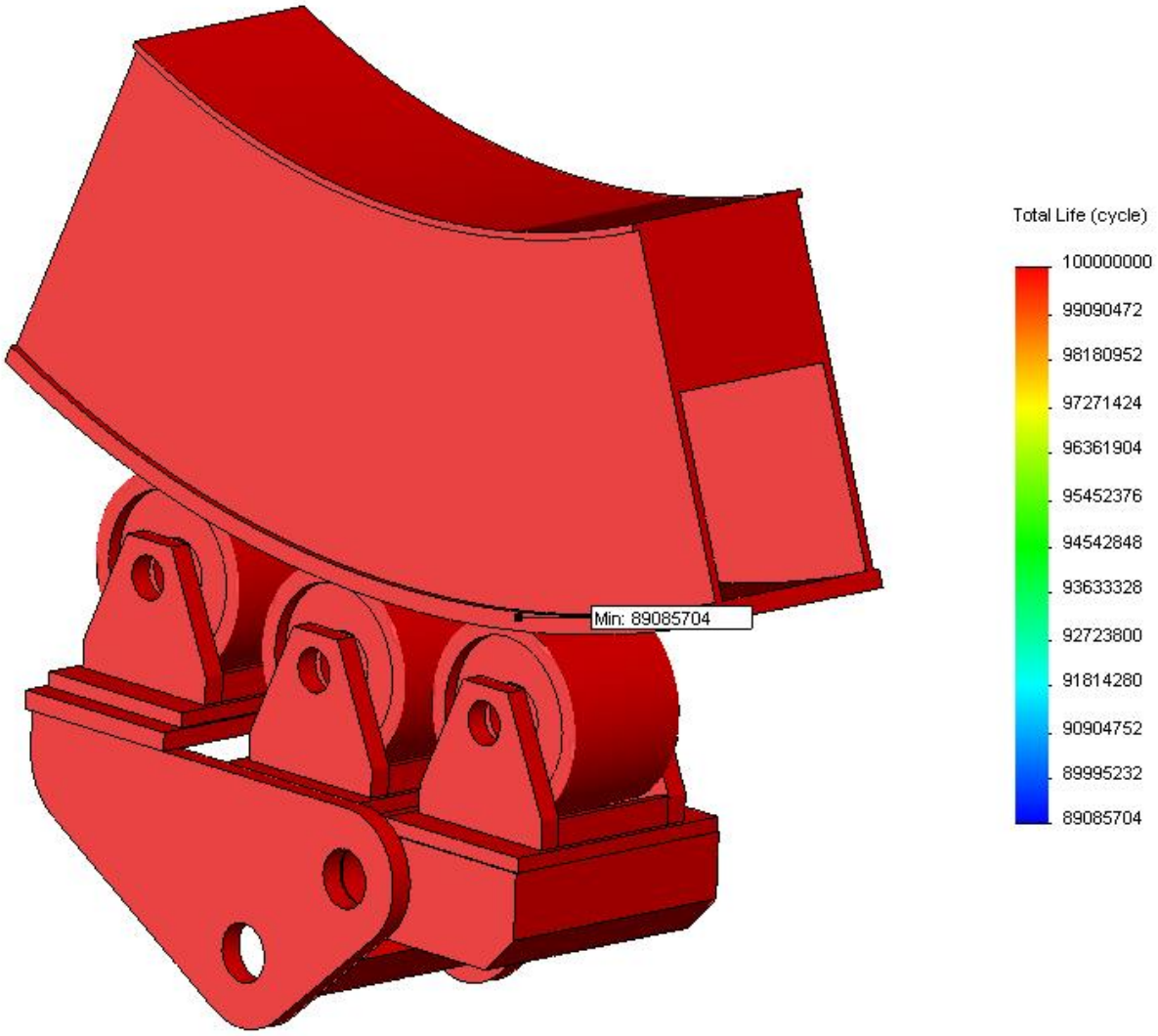
Maximal value of contact pressure is also computational peak value. When we disregard this computational peak value maximal value for contact pressure would be **113 N/mm^2.**

All following analysis including fatigue analysis for cylindrical rollers will be performed by using real stress value.



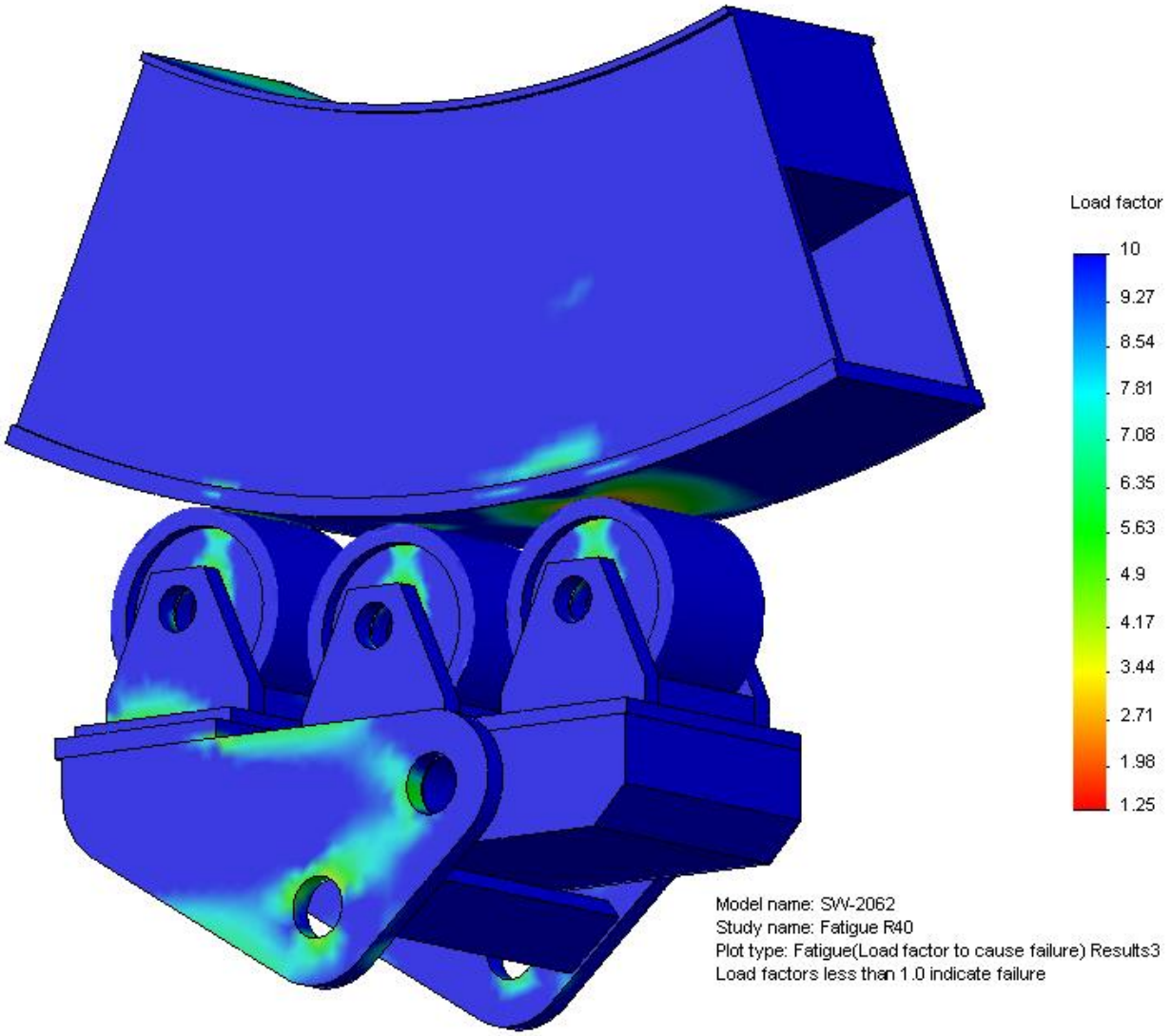
Fatigue Damage

26.7 % of life for the right roller area is consumed after 24000000 cycles. This is clearly small area and situation in reality is much better, when we disregard stress peaks



Fatigue – Total life cycle

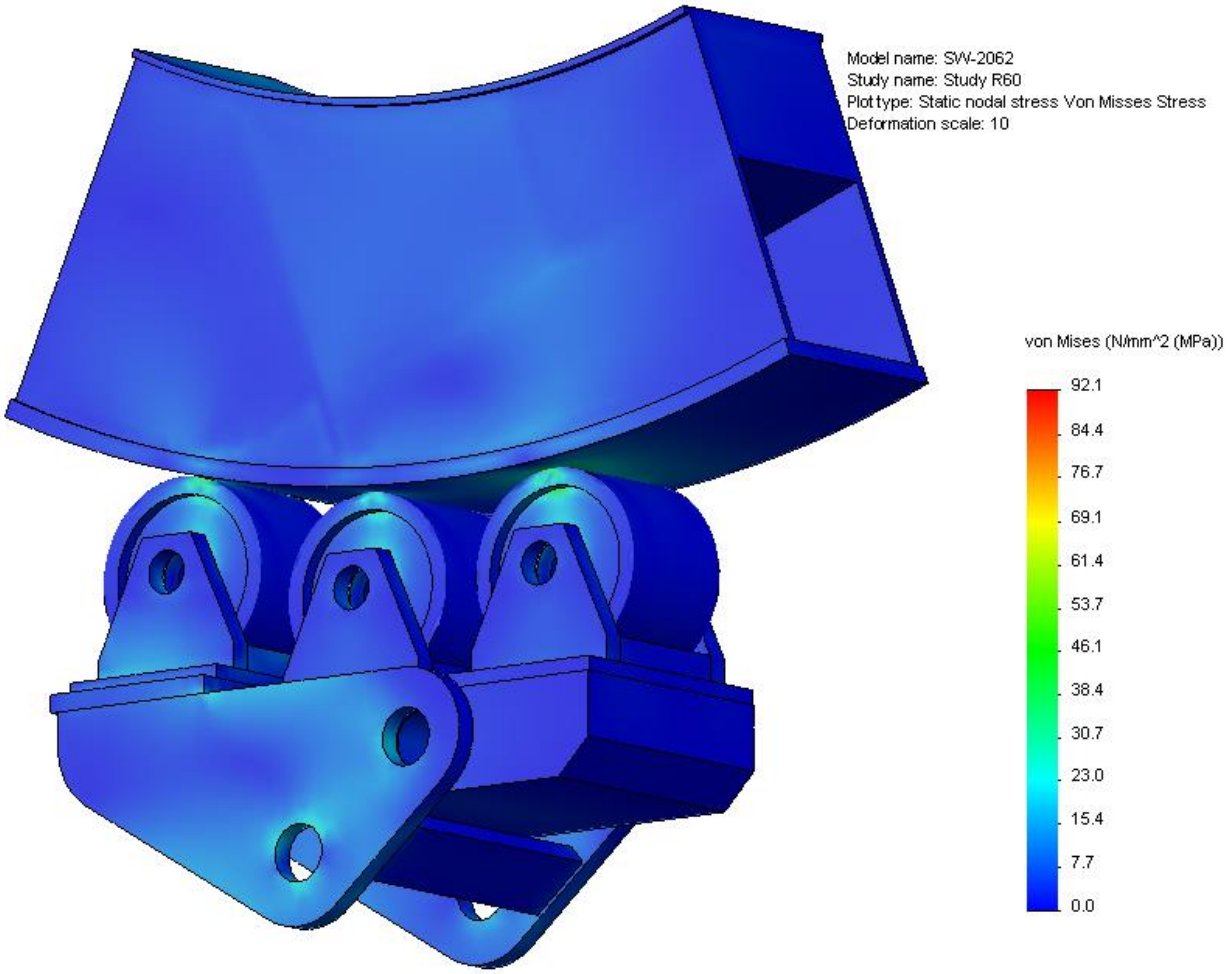
Fatigue will occur after 89085704 cycles, at the corner of the right most roller. In reality stress peak present in this area does not exist, so number of cycles is greater then mentioned.



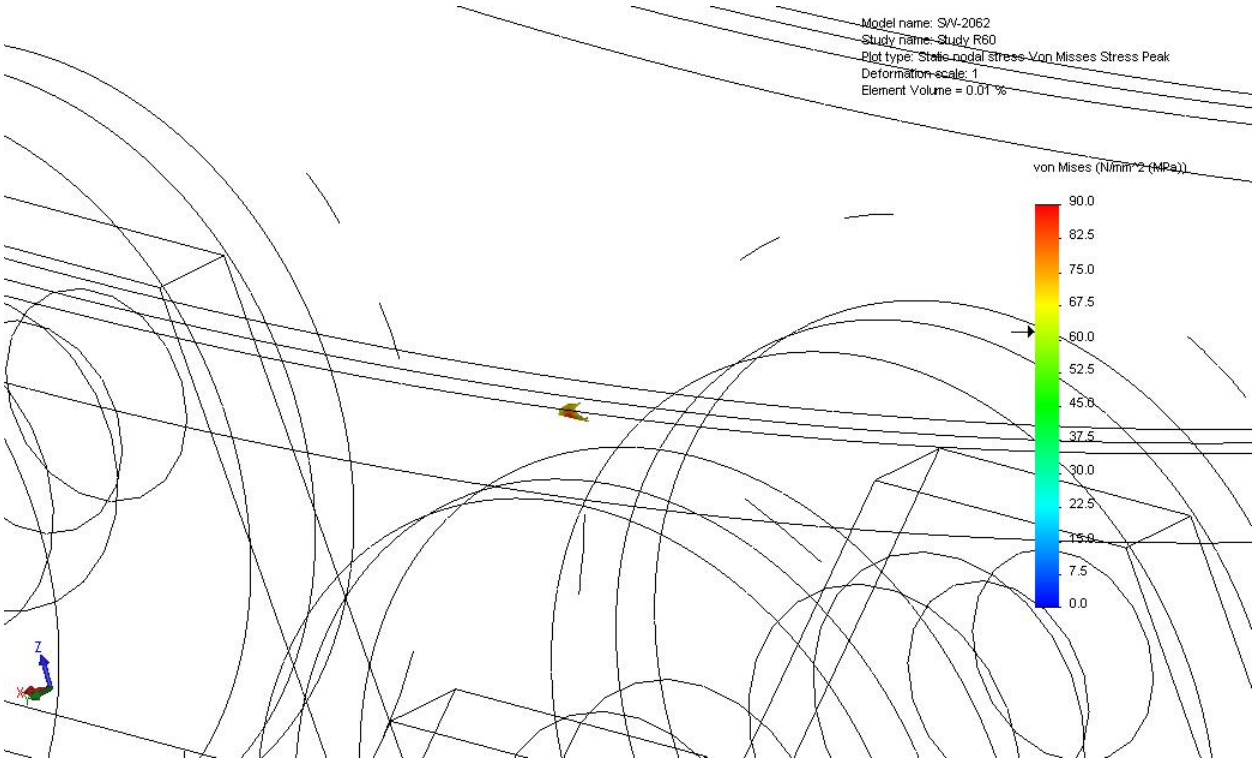
Fatigue – Load Factor

The design of ring and rollers subassembly will successfully achieve design goal of 15 years in operation.

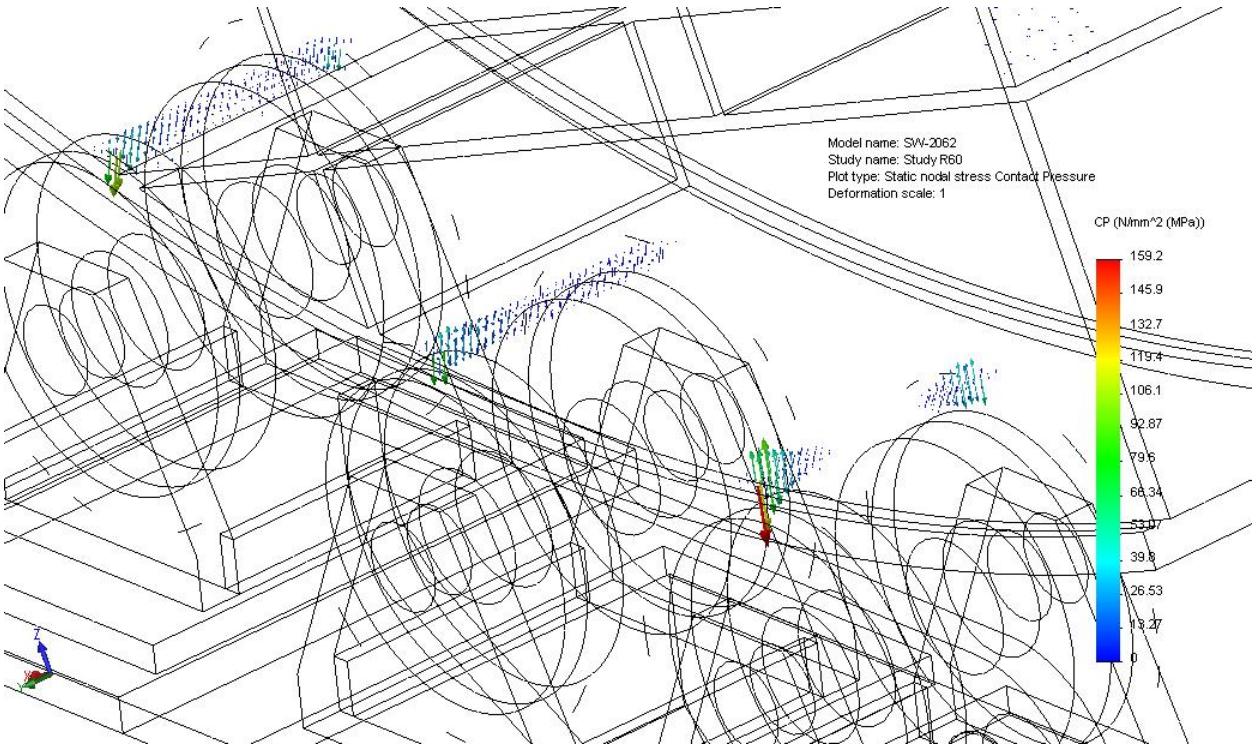
5.4. Analysis for the rollers with 60m camber radius



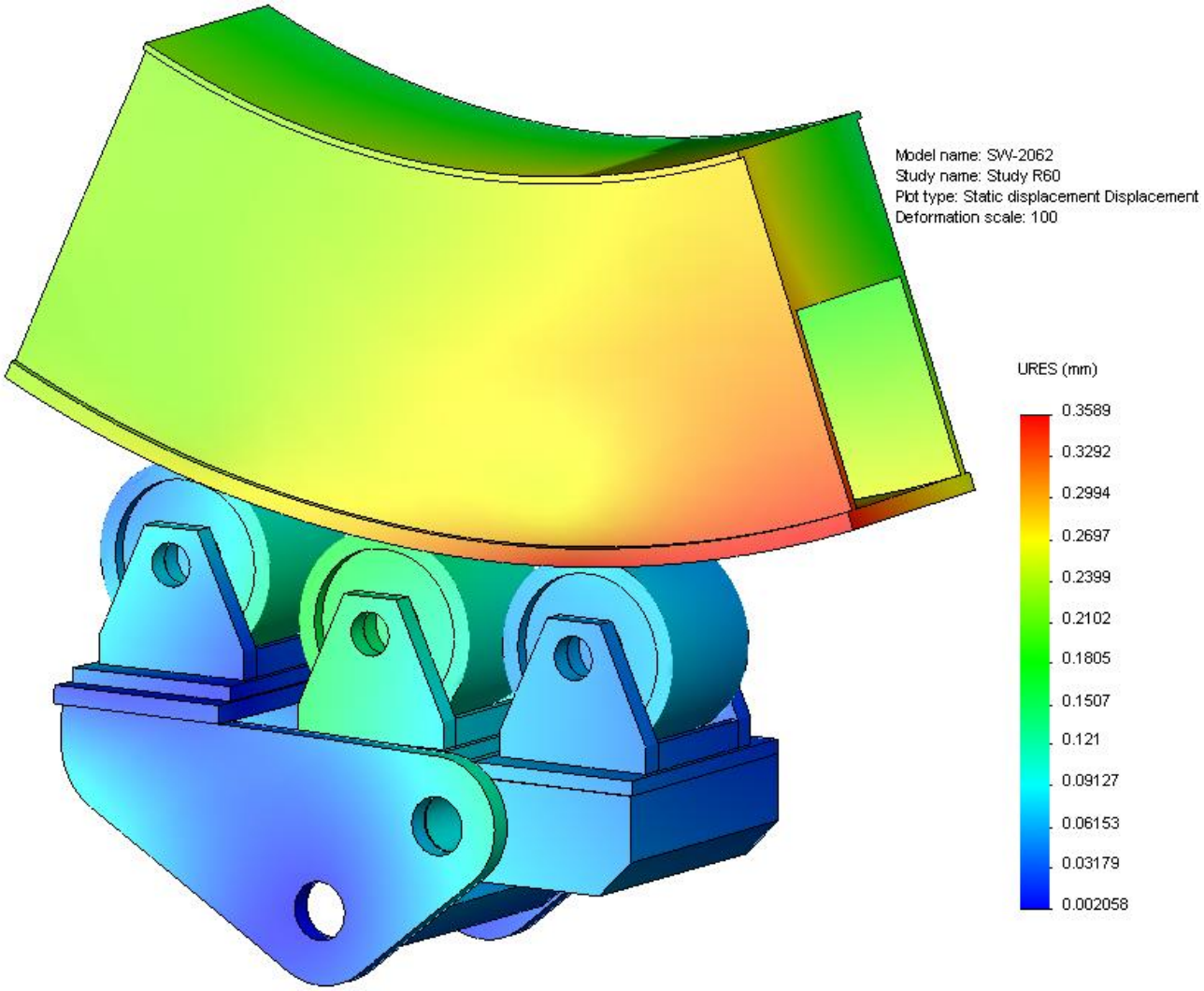
Von Misses Stress



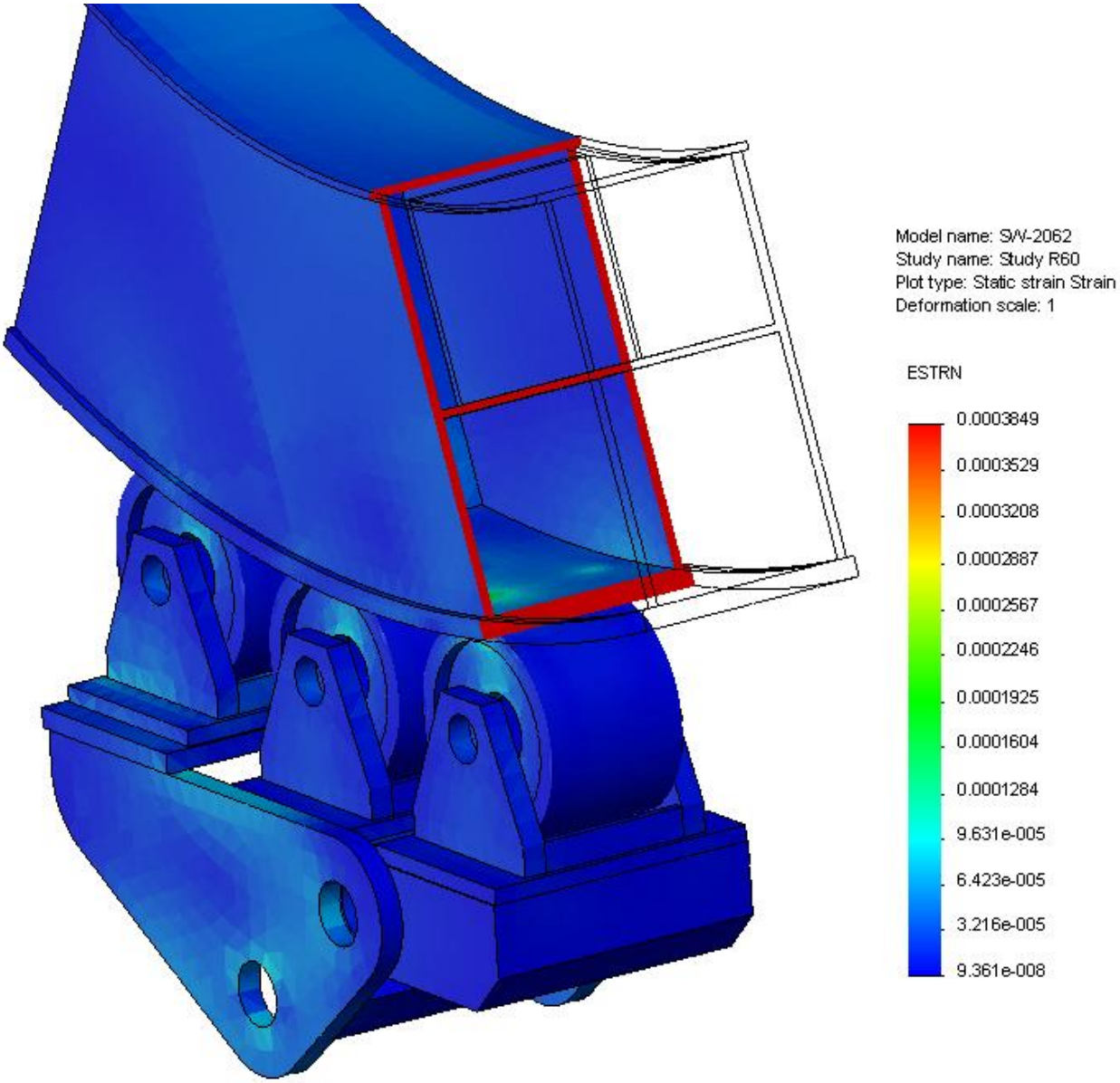
Von Misses Stress Peak



Contact Pressure



Displacement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Study name: Study R60
Plot type: Static strain Strain
Deformation scale: 1
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0.0001925
0.0001604
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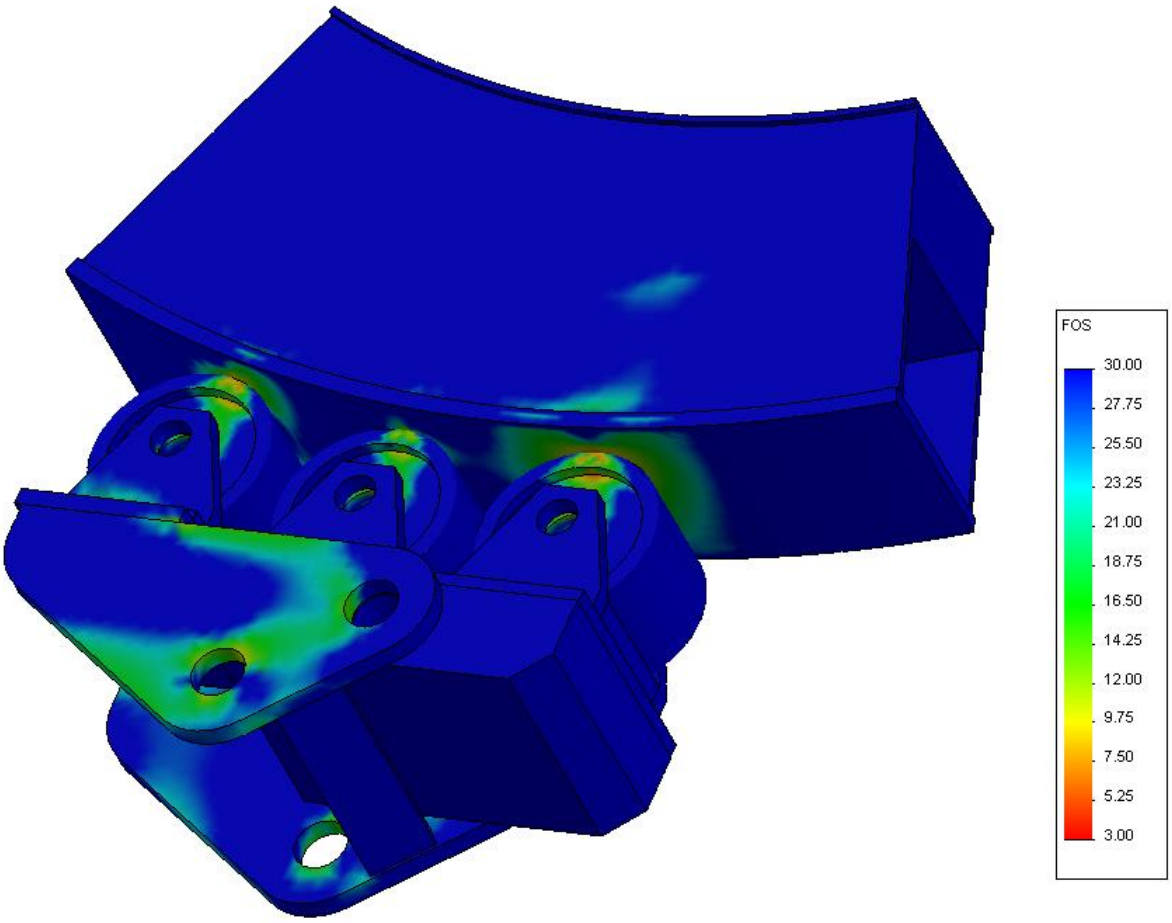
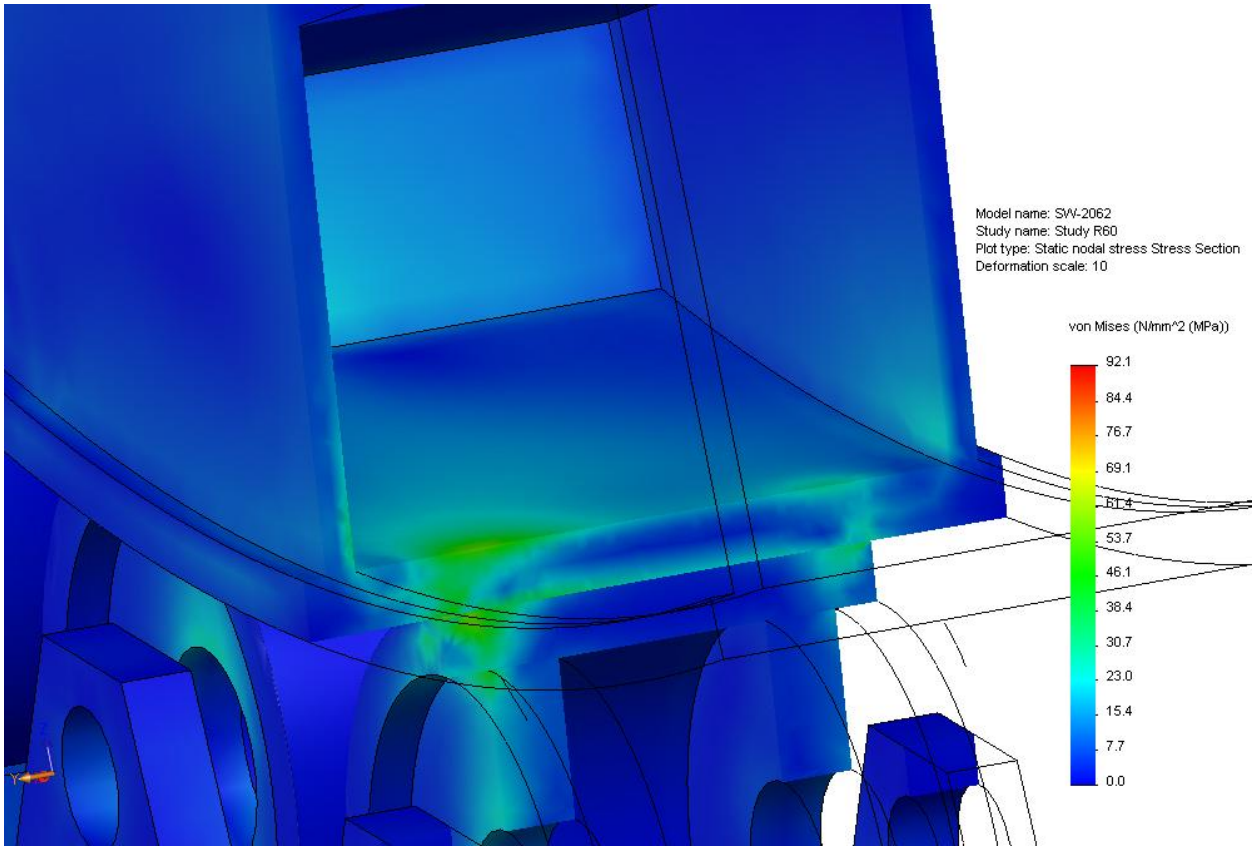
9.631e-005
6.423e-005
3.216e-005
9.361e-008

Strain



Factor of Safety

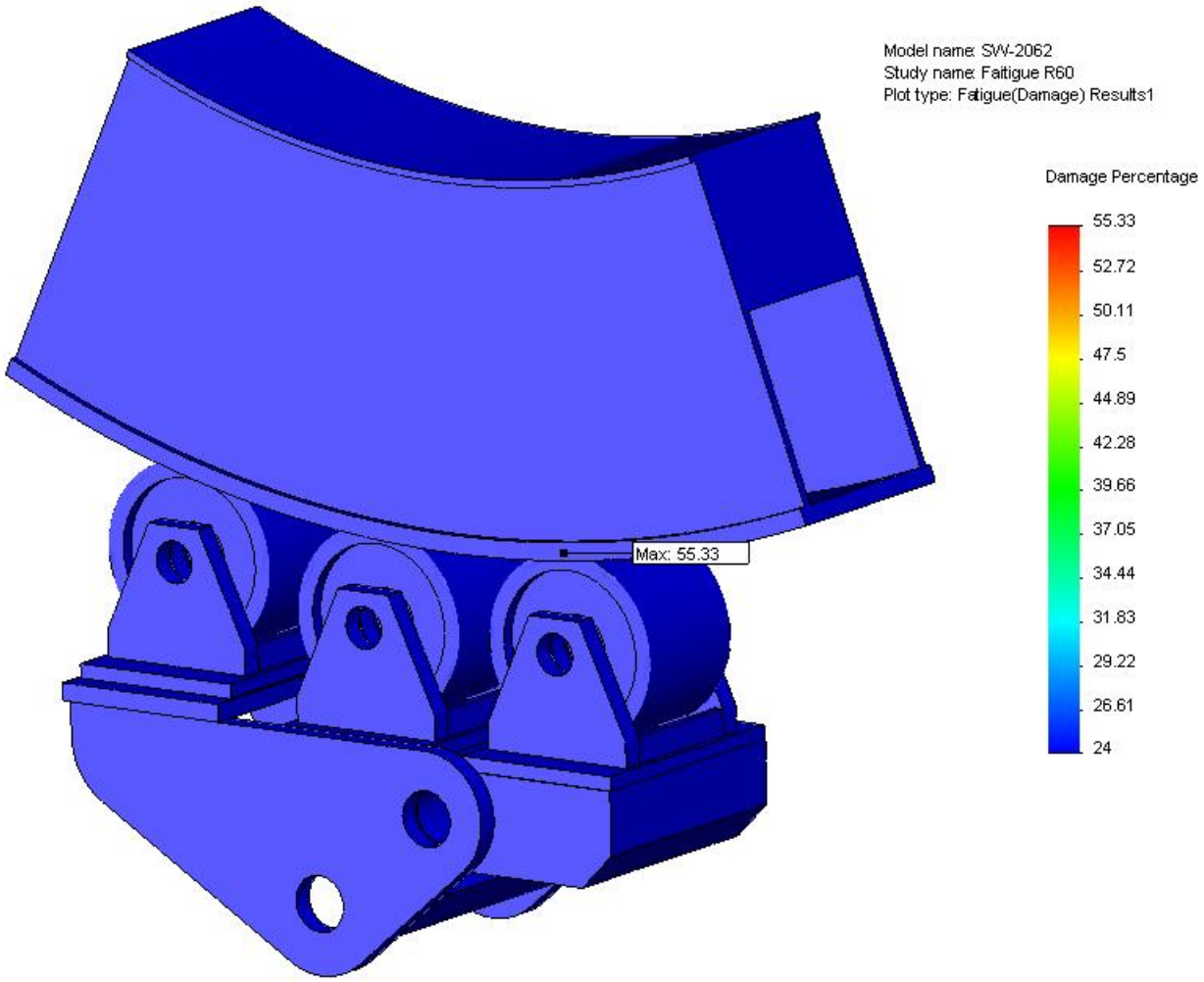


Von Misses Stress Section

Static stress analysis for cylindrical rollers showed peak value in the spot area on one of the rollers. When we disregard this computational peak value, the maximal Von Misses stress value should be about **84 N/mm²** .

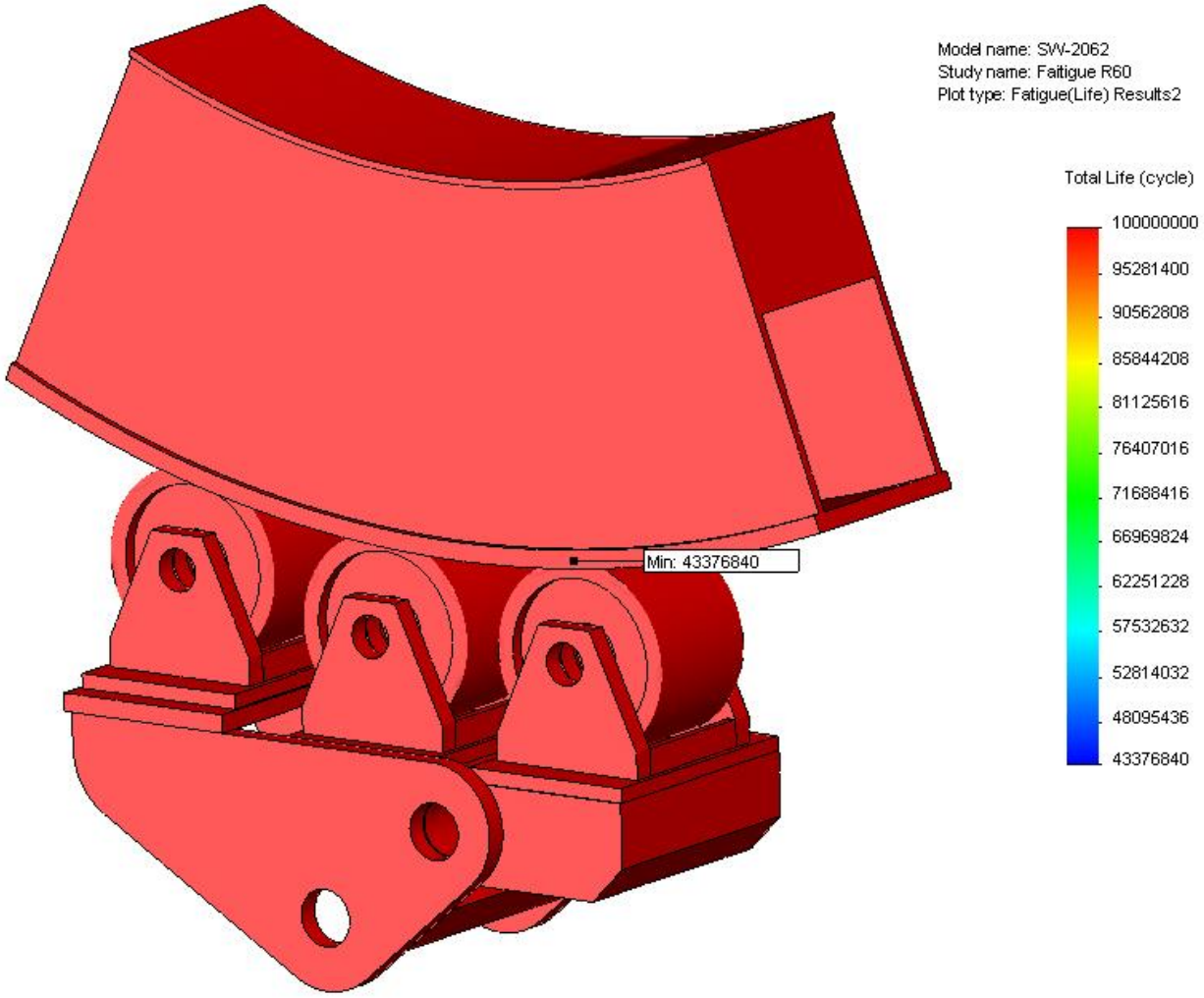
Maximal value of contact pressure is also computational peak value. When we disregard this computational peak value maximal value for contact pressure would be **145 N/mm².**

All following analysis including fatigue analysis for cylindrical rollers will be performed by using real stress value.



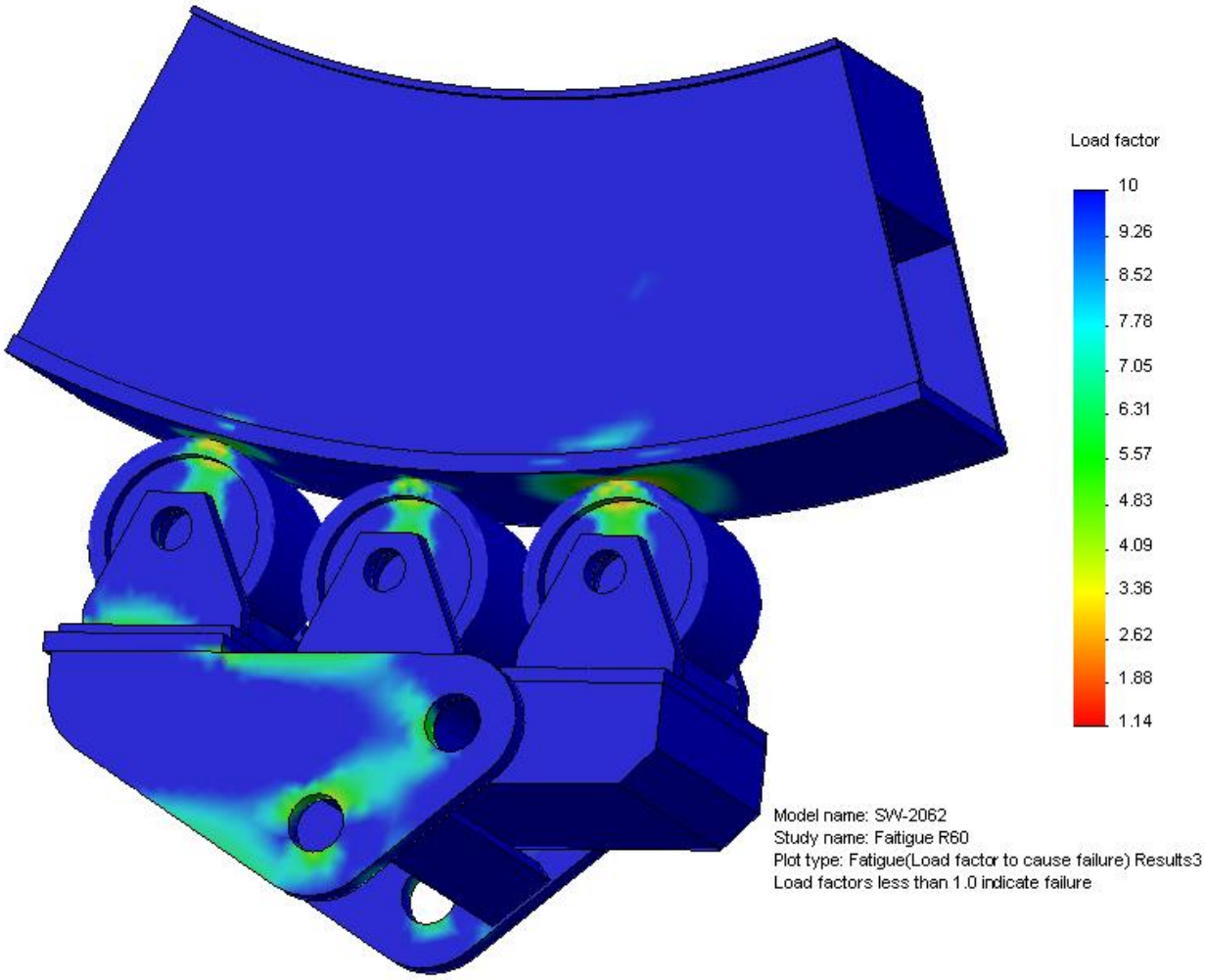
Fatigue - Damage

55 % of life for the right roller area is consumed after 24000000 cycles. This is clearly small area and situation in reality is much better, when we disregard stress peaks.



Fatigue – Total Life Cycle

Fatigue will occur after 43376840 cycles, at the corner of the right most roller. In reality stress peak present in this area does not exist, so number of cycles is greater then mentioned.



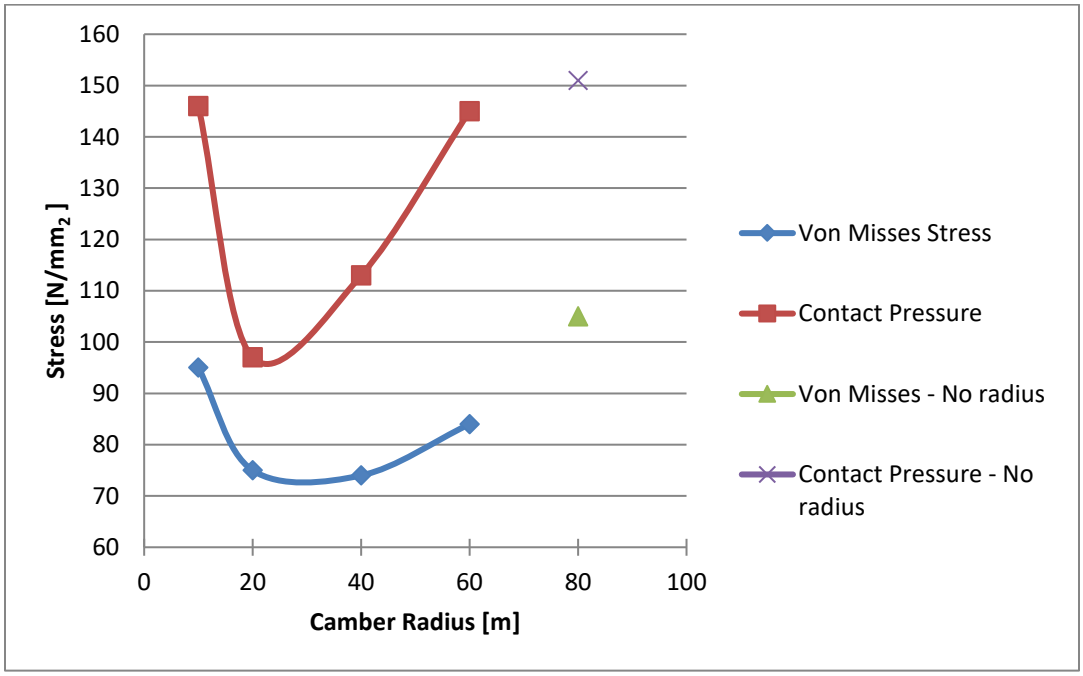
Fatigue – Load Factor

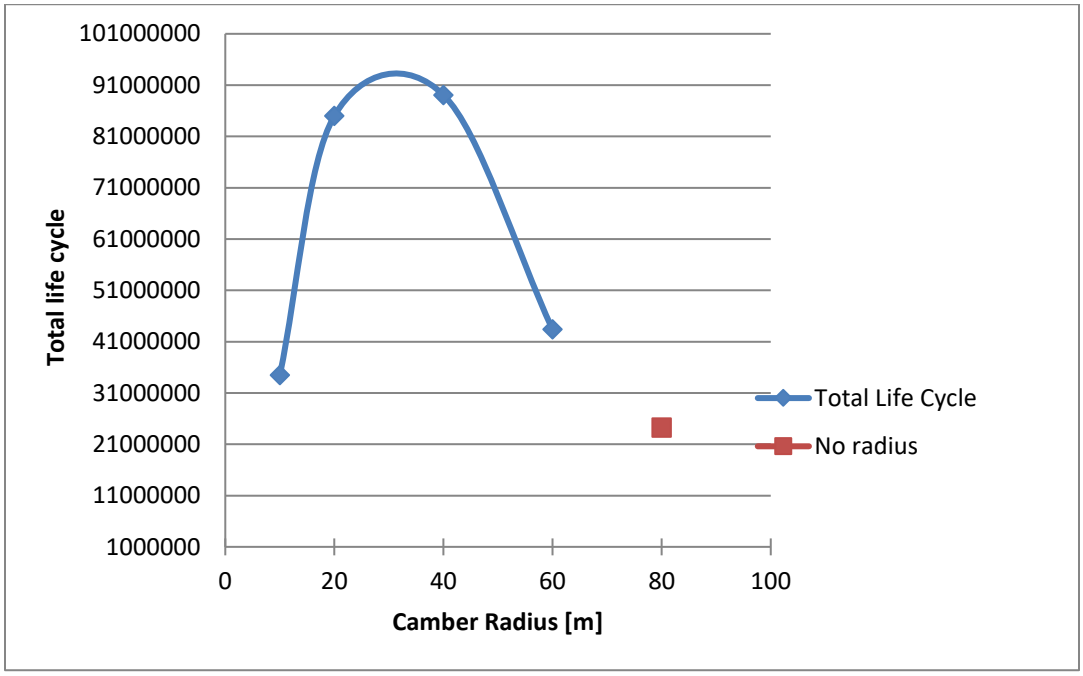
The design of ring and rollers subassembly will successfully achieve design goal of 15 years in operation.

6. CONLUSIONS

On the basis of the results obtained by previous calculations for different camber radius of the rollers we can summarize most important results in the following table and diagrams:

	Camber radius [m]				
	R10	**R20**	**R40**	**R60**	**No radius**
Von Misses Stress [N/mm²]	95	75	74	84	105
Contact Pressure [N/mm²]	146	97	113	145	151
Fatigue Life Cycle [n]	34493040	85028360	89085704	43376840	24244218





According to shown results the following conclusions can be made:

- Basic assumption which was made is uneven influence of distributed mass on the ring surfaces which causing unevenly distributed load on the surface of the rollers. The mentioned influence is decreased when we have smaller camber radius. It actually means that when we increase the radius, or In case that we have cylindrical roller we also have a higher stress concentration on the roller edges.
- If we continue to decrease the radius it will causing the lower stress concentration on the roller edges, but the contact pressure and Von Misses stress will be higher which can decrease life cycle of the rollers.
- Upon performed FEA and Fatigue analysis rollers with camber radius from 20 to 60 m are all acceptable, but when we take in consideration surface of contact area, Von Misses stress, Contact pressure and Total Life Cycle we can conclude that optimal solution for the camber radius should be from 40 to 60 meters.
- Cylindrical rollers can also fully satisfy operating and fatigue requirements of the Front Roller Assembly.