Altair Simulation challenge
IITG Racing
Sprocket Optimization Report

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1 Introduction

Sprockets are one of the most common devices , widely used in power transmission. They serve as an integral component to transmit power between shafts by means of an intermediate chain.One more advantage is that they can be used to alter the angular velocity with which the power is transmitted.Even though the teeth of sprocket and the points of attachments are expected to be at high stress , the same need not be true for the entire body. While a complete flat plate with teeth may get the job done , all the material in it are not essential for its safe functioning . Rather these excess materials just increase the mass without much contribution to stress bearing capability of the sprocket. In an event like Formula Bharat , where every kilogram counts , the natural progression is to decrease the mass of the sprocket and achieve the required stress bearing capability with minimal mass.

In this report , the general processes followed have been discussed briefly , which includes

- Initial CAD design
- Estimating working conditions
- Replication of working conditions in the Altair Inspire software
- Analysis of this initial model
- Optimization of the model
- Final analysis

2 Initial model data

The initial CAD model of sprocket was created according to geometrical requirements of assembly.The Specifications of initial model are as in table 1 and in figure 1.

Table 1: Unoptimized sprocket specifications

Outer diameter	21cm
Inner diameter	20cm
Pitch diameter	20.5cm
Hollow region diameter	11cm
Distance of support holes from center	7cm
Width of support holes	8mm
Number of support holes	8
Number of teeth	67
Width	5.5mm
Mass	0.324kg
Material	Aluminium(7050-T6)

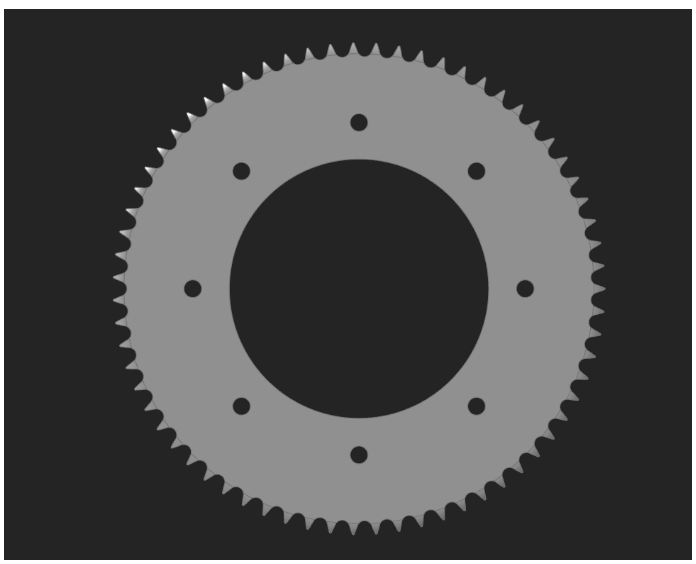


Figure 1: Unoptimized sprocket

3 Operating Conditions

The Sprocket is attached to motor through bolts at the eight support holes , and thus rotates along with the motor. A chain runs over the teeth of sprocket which connects to another sprocket.The following data has be derived from the working conditions:

Torque on sprocket	140 Nm
Angle of contact	230.1^o
Number of teeth in contact	43

Table 2: Loads and configuration

Total tangential force on sprocket $F_{total} = Torque/Radius = 140/0.1025 = 1368.5239N$. The the force distribution on each tooth which is in contact with chain is given by :

$$T_k = T_o \times (sin(\phi)/sin(\phi + 2\beta))^{k-1}$$

where,
ϕ = Minimum pressure angle=$17 - 64/N_{teeth} = 16.0448^o$
2β = Sprocket tooth angle = $360/N_{teeth} = 5.3731_o$
T_o = Chain tension = $891.415N$
T_k = Force on k^{th} tooth

A program was written to calculate the forces on all 43 teeth , taking $\phi, 2\beta, T_o, k$ as inputs. The obtained data is shown in table 3.It is noticed that the force drops rapidly as k increases and it drops by a factor of about 10^{-6} by the 15^{th} tooth and hence force on further teeth of sprocket are neglected.

4 Analysis of the unoptimized model

The forces calculated are applied to the tooth accordingly and a fixed support is applied to all of the eight support holes. The material is assigned as Aluminium(7050-T6) and the model was analysed for the load case.It is observed that the stress levels (figure 2) are considerable only at a small region near the teeth and the regions nearer to the center bear only a very small stress (in the order of $10^3 MPa$).This shows that there is a lot of space for optimization , ultimately resulting in reduction of mass without affecting performance much.

5 Optimization of the model

The model is prepared for optimization by partitioning the teeth and support regions.Cyclic symmetry constrain is enforced about 8 plane passing though each hole and perpendicular to sprocket and the model is subjected to mass

k	Force
1	891.419
2	310.774
3	108.345
4	37.7721
5	13.1684
6	4.59089
7	1.60052
8	0.557985
9	0.19453
10	0.0678186
11	0.0236435
12	0.0082428
13	0.00287368
14	0.00100185
15	0.000349272

Table 3: Force calculated on each tooth of sprocket

optimization.The result is shown in the figure 4. As expected , the material towards center is redundant and materials are retained only towards the tooth and supports. Based on the inferred data and location of retained mass, an improved version of sprocket is designed.In this model, in addition to the regions traced by the software , two rings connecting all the six holes are added for operational safety , accounting for imperfections.The improved model is shown in figure 5.

6 Analysis of the optimized model

The optimized model is subjected to same loads and supports applied to the unoptimized model and the results are shown in the figures 6,7 and 8. About 64% of mass has been reduced with only a very small change in the minimum factor of safety and maximum stress.

Parameter	Unoptimized model	Optimized model	Percentage change
Mass	0.324kg	0.116	-64.198%
Max.Stress	$1.494 \times 10^8 MPa$	$1.782 \times 10^8 MPa$	+19.277%
Min.Factor of safety	2.8	2.3	-17.857%

Table 4: Comparison of optimized and initial design of sprocket

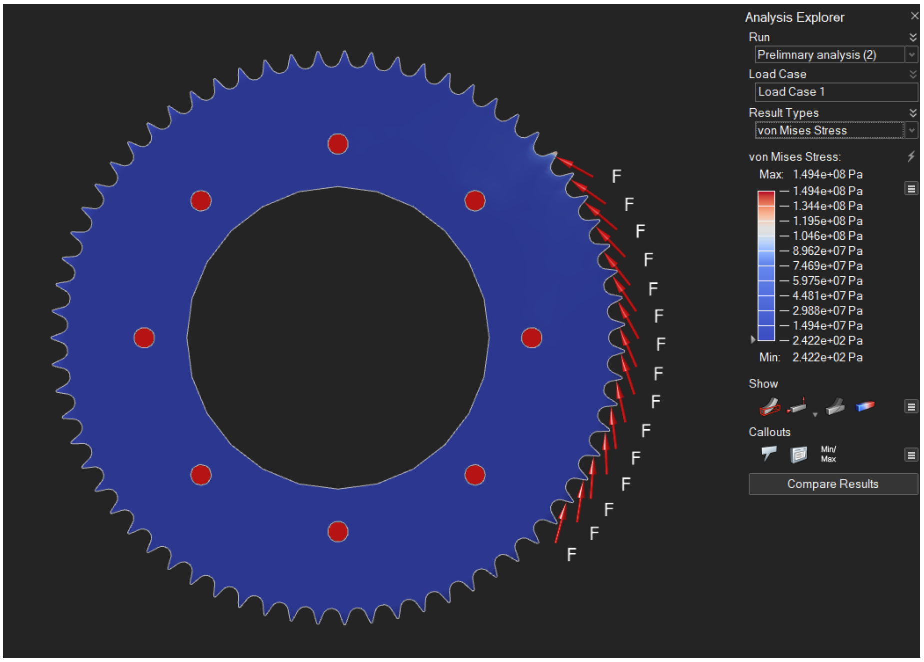
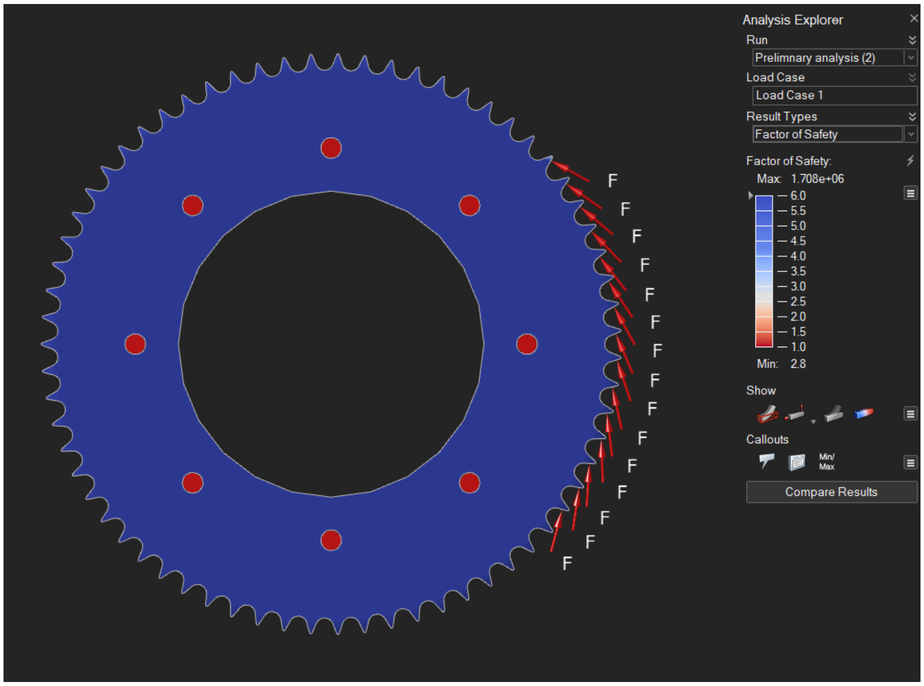
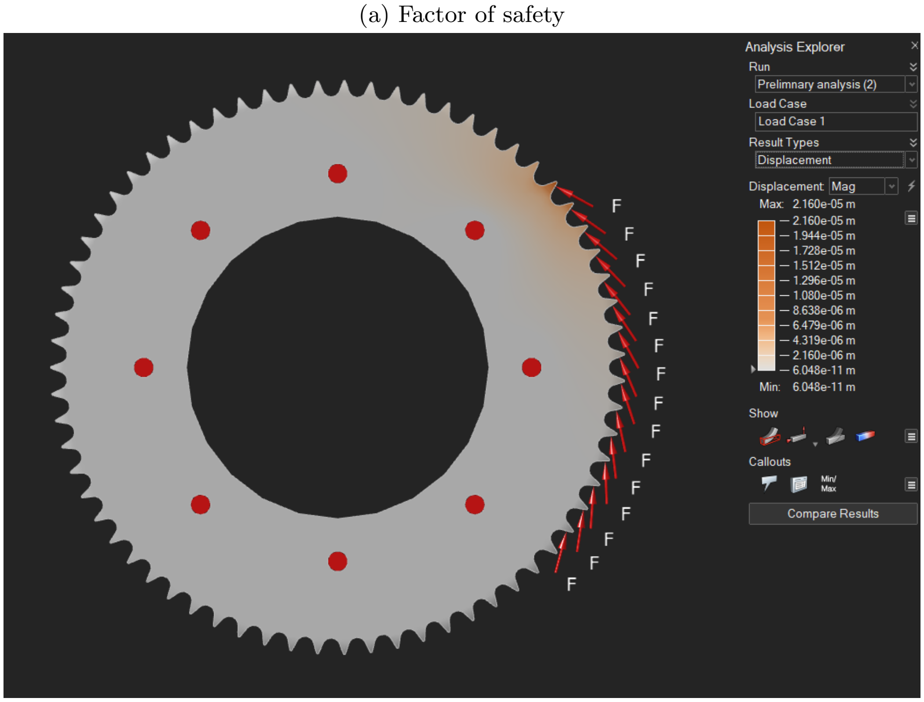


Figure 2: Stress distribution on unoptimized sprocket



(a) Factor of safety



(b) Displacement

Figure 3: Factor of safety and displacement in unoptimized model

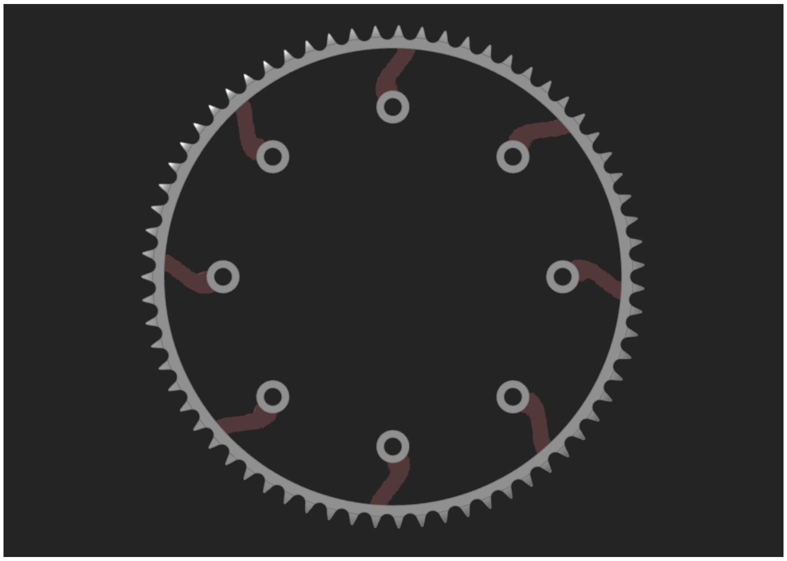


Figure 4: Optimization result

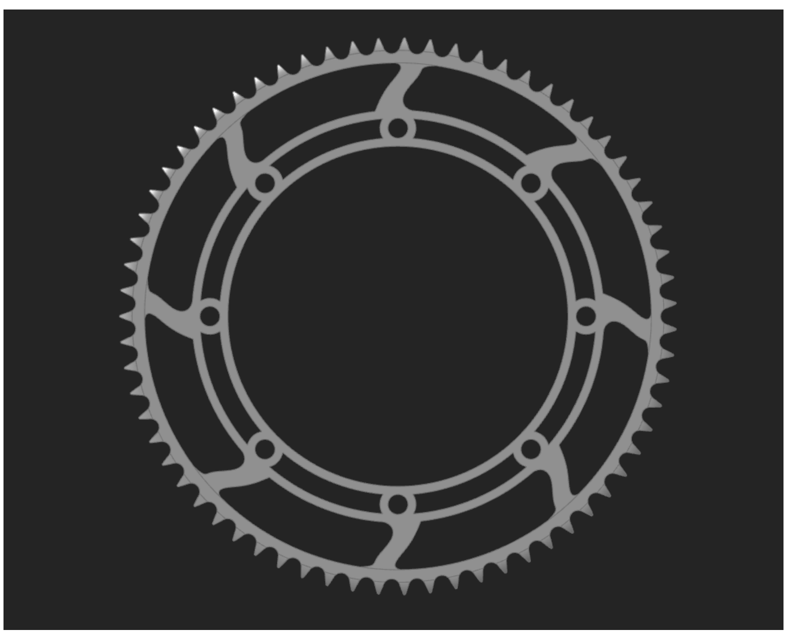


Figure 5: Optimized design

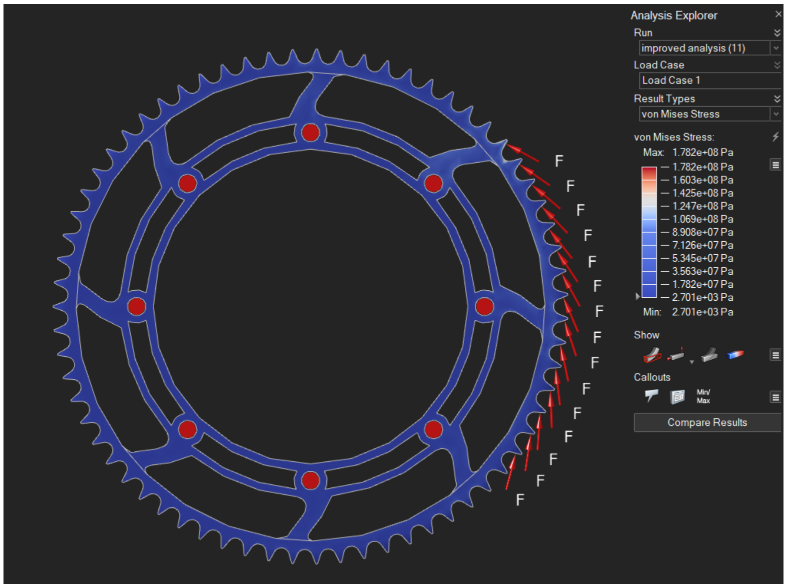


Figure 6: Optimized design - von Mises stress

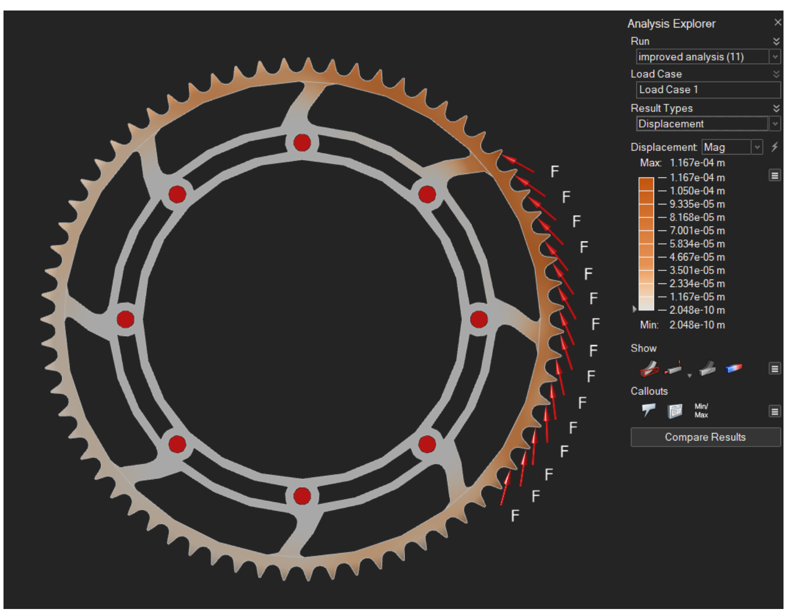


Figure 7: Optimized design - Displacement

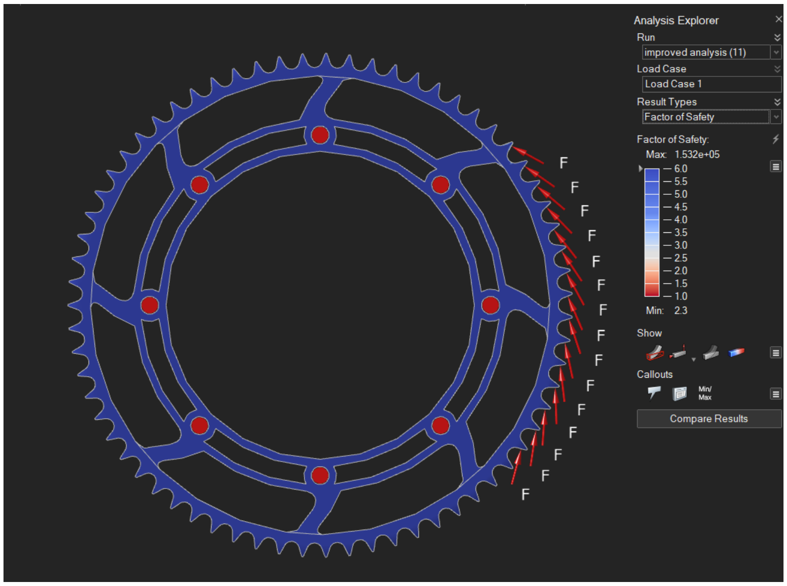


Figure 8: Optimized design - Factor of safety