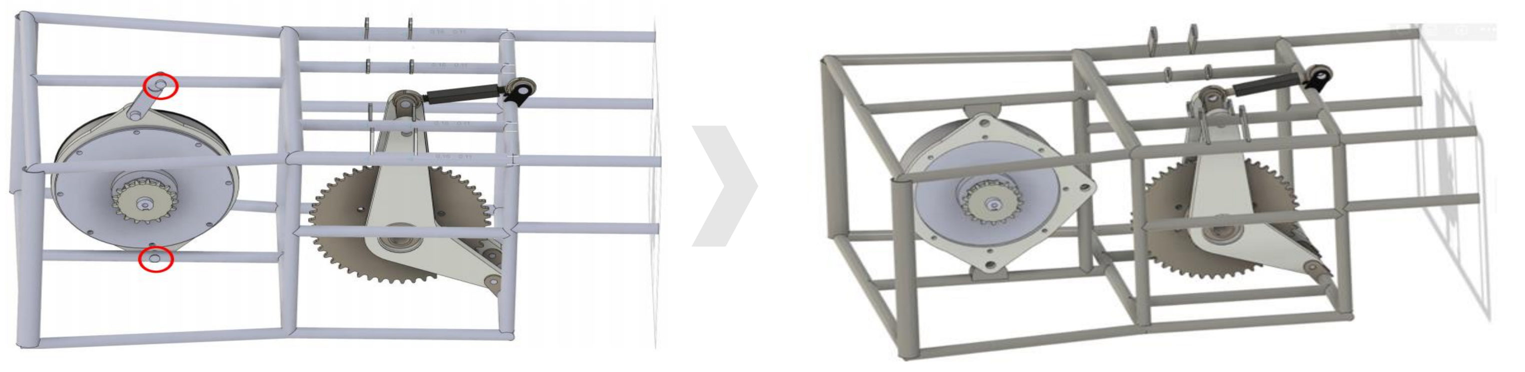
Enhancement of Motor Frame for Improved Driving Stability in a Custom-Built Automobile

Min-woong Han
Seung-eun Hwang
Hyeon-ho Moon
Chong-Sun LEE

Problem statement

In this study, the goal is to analyze the effects of forces occurring in the rear parts of a self-made electric vehicle and conduct analysis of an improved model. The main forces acting on the rear part include chain tension, generated by driving the motor, suspension force, and etc. In actual vehicle operation, there were two major problems:

1. Chain loosening problem due to horizontal rotation of motor
2. Occurrence of material yield of specific frames



(a) (b)

Figure 1. Old model (a), developed model (b)

Simulation setting

1. Material used in analysis

Many parts are used in vehicles, such as chain sprockets, LSD, motor cases, fastening bolts, etc. The actual parts and materials used, and their physical properties are as follows. Parts not significantly needed for analysis were set to structural steel.

Table 1. Component & material

Component	Material	*Elastic*	Yield Strength	Tensile strength
Main body (frame)	SM45C	205 $[GPa]$	370 $[MPa]$	540 $[MPa]$
Chain sprocket	SM45C Induction hardening Anodized	Much higher than frame		
LSD, motor case	AL6061-T6	70 $[GPa]$	276 $[MPa]$	310 $[MPa]$
Bracket (case – frame)	SM45C	205 $[GPa]$	320 $[MPa]$	540 $[MPa]$
Other components	Structural steel	200 $[GPa]$	250 $[MPa]$	400 $[MPa]$

2. Connection condition setting

Bonding was performed on all bolts and connections between axes. The connection conditions for contact between the motor case and frame were set to frictional conditions. At this time, the friction coefficient was set with 0.5. In addition, revolute joint connection conditions were set for the turnbuckles and brackets of the frame used behind.

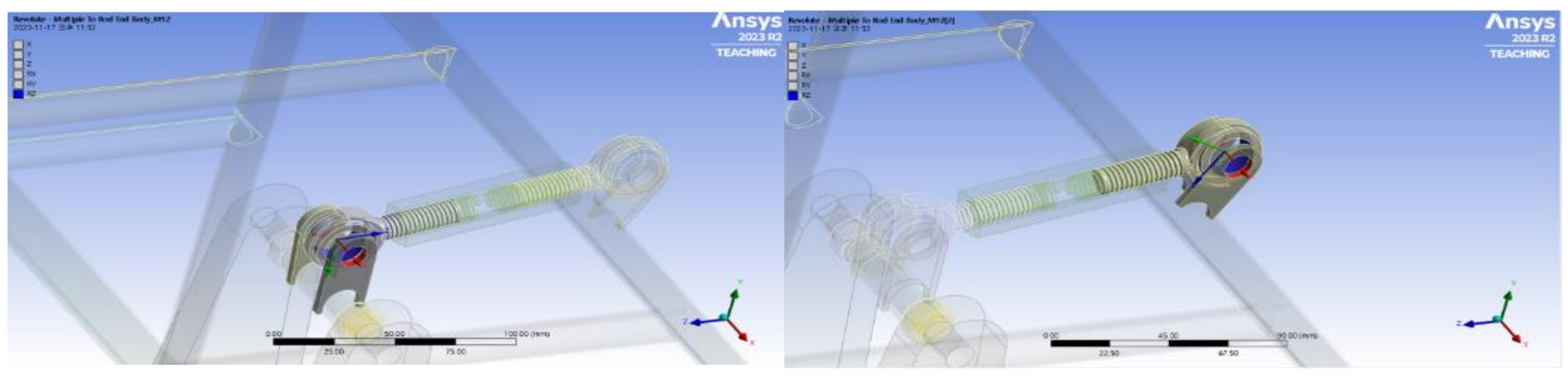


Figure 2. Revolute joint condition

3. Boundary condition setting

Considering the point welding condition of the frame used in the car, the edge line of vertical frames set with fixed support. And some horizontal frames those are connected with bracket with upper and lower arm, are set with remote displacement. Translational y and rotational z component as free, and others are set with 0.

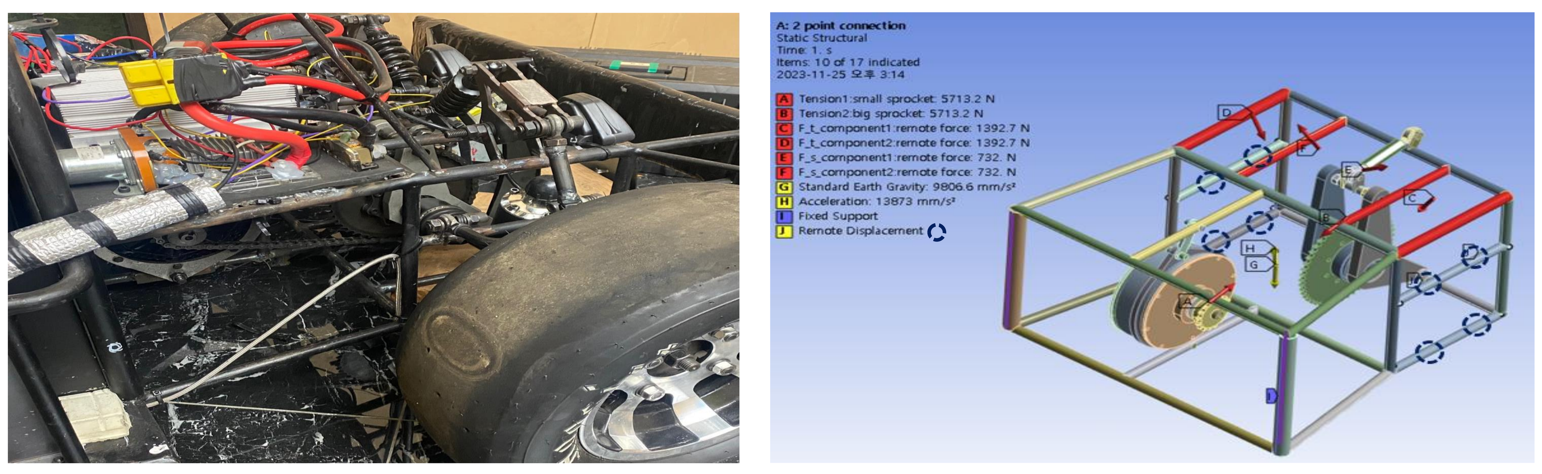


Figure 3. Analysis condition

4. Chain tension

The tension generated according to the maximum driving specifications of the motor was considered. Also, considering conditions such as impact coefficient, usage coefficient, etc., a force of about 3.84 times was considered. In addition, since the chain is designed with a safety factor of 10 in mind, the maximum force that occurs during sudden stops or acceleration was multiplied by about 7.68 times.

Table 2. Material information

Specifications	Values
Maximum rpm	3103 $[rpm]$
Rated power	8.8 $[kW]$
Mass of motor	11 $[kg]$
Diameter of small sprocket	69.12 $[mm]$
Horizontal angle of chain	14.8263 $[deg]$

$$\omega = 3103[rpm] = 324\,[rad/s], \qquad power = 8.8[kw]$$

$$\phi = 69.12[mm], \qquad \theta = 14.82°$$

$$\tau = \frac{power}{\omega} = 27.1\,[N \cdot m], \qquad T = \frac{\tau}{\phi/2} = 784[N]$$

$$coef_{use} = 1.2, \qquad coef_{vel} = 1.6$$

$$coef_{impact} = 1.93, \qquad coef_{static} = 2.0$$

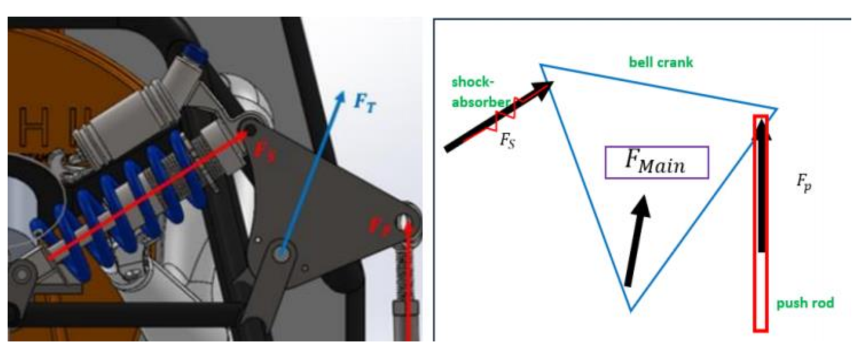
$$T_{max} = coef_{static} \cdot coef_{use} \cdot coef_{vel} \cdot coef_{impact} \cdot T = 5.81[kN]$$

$$T_{\max hori} = T_{max} \times \cos\theta = 5.61\,[kN]$$

$$T_{\max vert} = T_{max} \times \sin\theta = 1.49\,[kN]$$

5. Bell crank part

The force of the pushrod transmitted to the bell crank attached to the frame above the rear of the car is first calculated. Then, the suspension force(F_s) and bell crank support force(F_{main}) are obtained through static analysis. All relevant values were taken from the referenced papers and used.



$$F_s = 732\,[N]$$

$$F_{mx} = 682.1\,[N]$$

$$F_{my} = 1214.2\,[N]$$

$$F_{sx} = 577.1554\,[N]$$

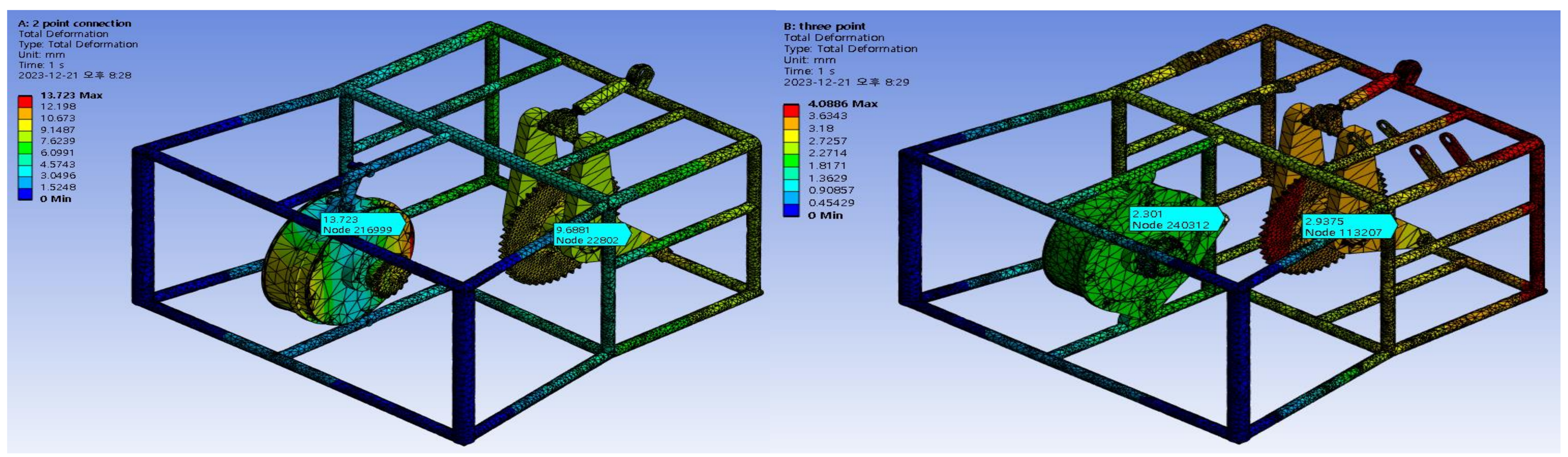
$$F_{sy} = 450.2396\,[N]$$

Figure 4. Forces related to bell crank part

Deformation

Table 3. Comparison of deformation value

Old model		Developed model	
Direction	Values $[mm]$	Direction	Values $[mm]$
X	13.7	X	1.00
Y	1.94	Y	2.17
Z	3.06	Z	1.00
Total deformation	13.7	Total deformation	2.31



(a) (b)

Figure 5. Total deformation (a) old model, (b) developed model

The improved model shows a significant reduction in X-direction deformation compared to the problematic model, and there is also a noticeable decrease in Y-direction deformation.

Static analysis

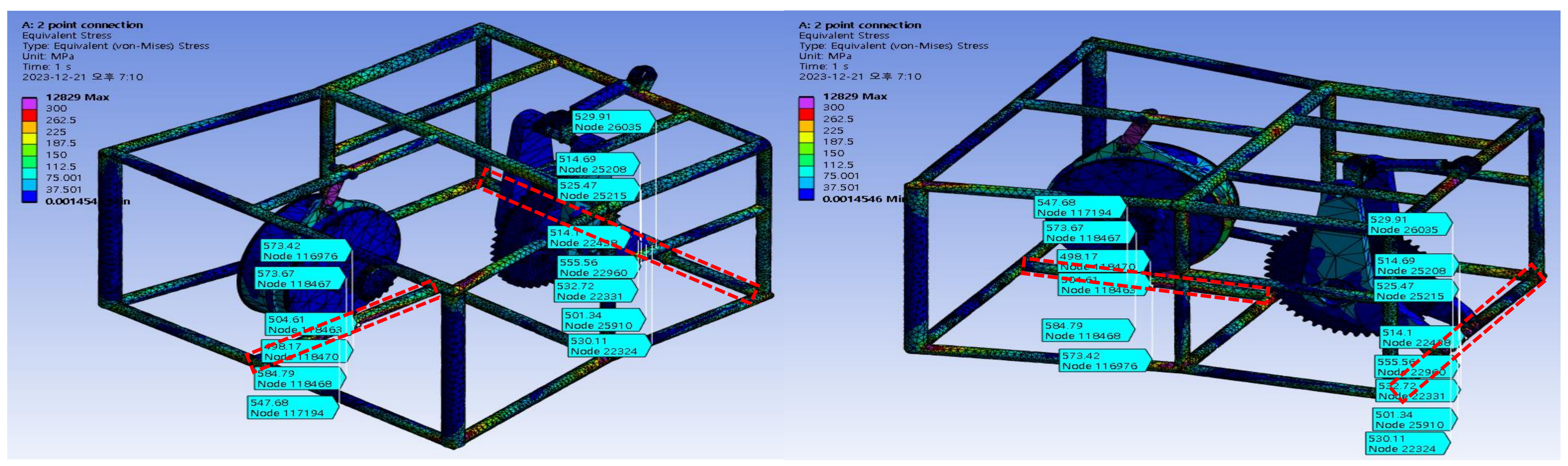


Figure 6. Equivalent stress of problem model (yield condition)

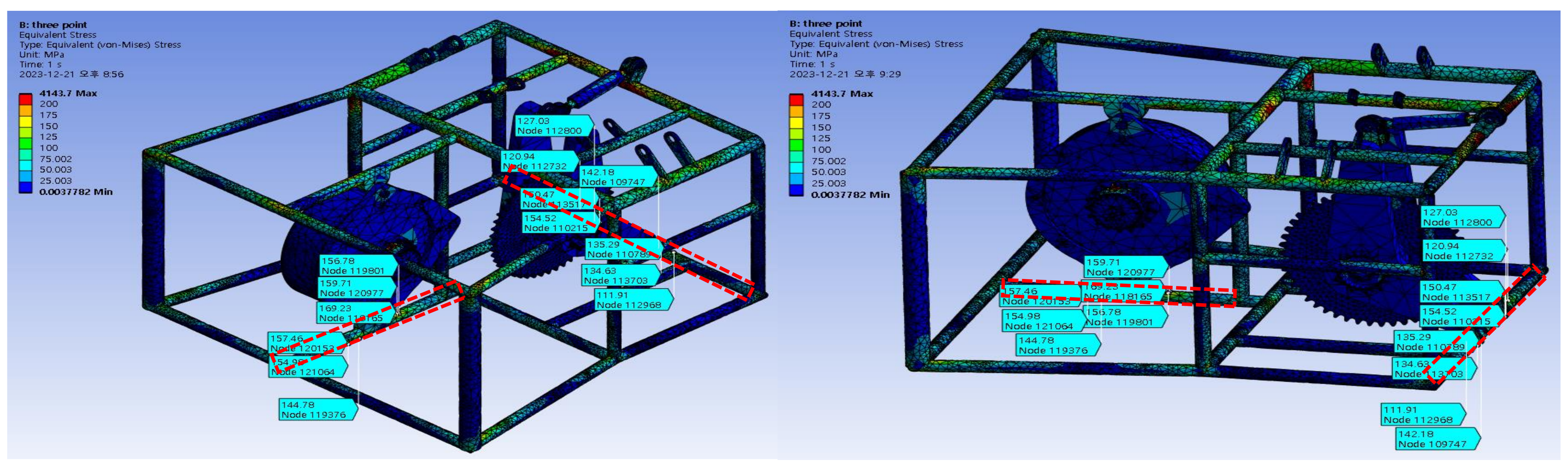


Figure 7. Equivalent stress of developed model

Table 4. Comparison of equivalent stress

Model	Main equivalent stress	Frame condition
Problem model	547 $[MPa]$, 526 $[MPa]$	$\sigma_{equivalent} > \sigma_y$
Developed model	157$[MPa]$, 135 $[MPa]$	$\sigma_{equivalent} < \sigma_y$

The results of the problem model and the development model show that the stress in the development model has decreased by approximately 70% compared to the problem model.

Fatigue analysis

Table 4. Condition for fatigue analysis

Parameter	Values
Stress type	Zero-based
Stress theory	Goodman
Scale factor	0.5
Fatigue strength factor	0.5

$$\text{Goodman}: \frac{\sigma_a}{\sigma_e} + \frac{\sigma_m}{\sigma_{ut}} = \frac{1}{N}$$

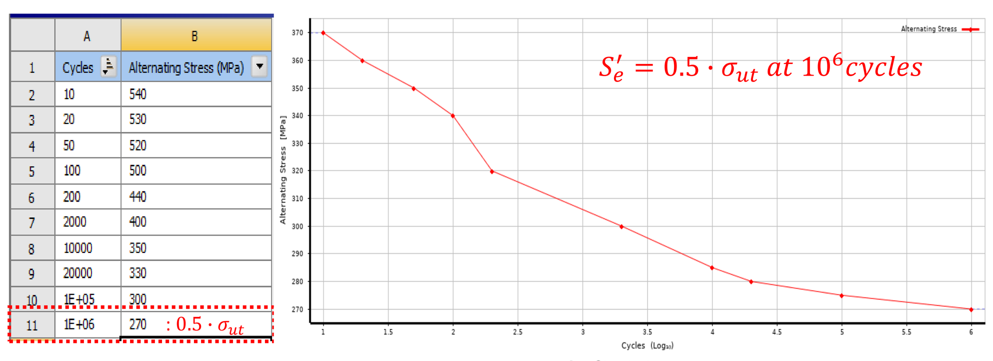


Figure 7. SN curve definition

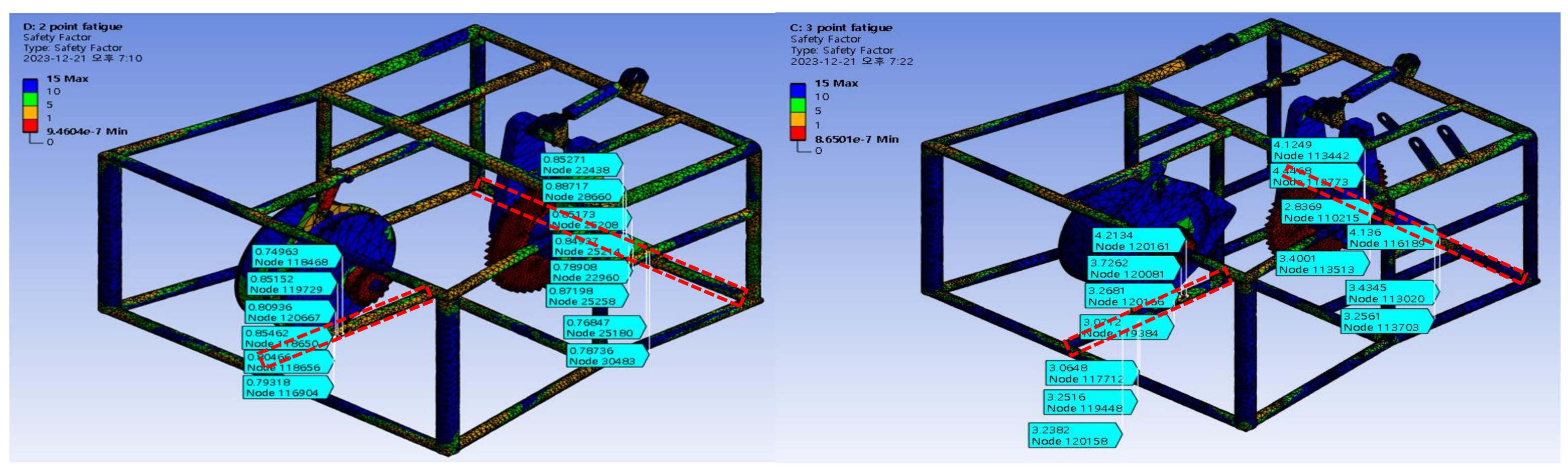


Figure 9. Fatigue analysis result of problem model(left) and developed model (right)

Table 6. Comparison of safety factor at 10^5 cycle condition

Model	Safety factor (avg)	Frame condition
Problem model	0.81, 0.83	Yield state
Developed model	3.32, 3.66	Safe state

The Safety Factor in the development model is observed to have increased by approximately fourfold compared to the problem model.

Conclusion

Using ANSYS software, it was possible to analyze the structural deformation or stress caused by the force generated by the motor drive of the self-made electric vehicle. Everything was analyzed under maximum conditions, and analysis was conducted on the model in question and the two improved models. As a result, the improved model was able to reduce stress and secure fatigue safety factors in areas that were problematic in the existing model.