CAE Project

2012012156 배석환
2013020574 이수명

목차

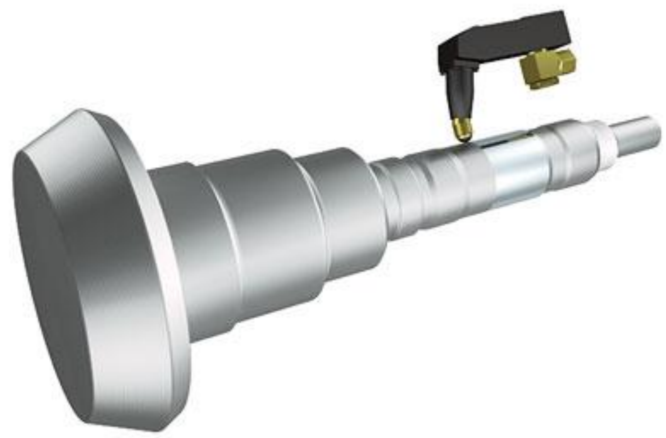
팀명-수석

국어 사전

수석 (首席) ★ 다른 뜻(5건) | 맞춤법·표기법

[명사] 등급이나 직위 따위에서 맨 윗자리.

Gear Shaft



기어 샤프트를 선정한 이유

- 자동차와 설계를 연계하는 해석
- 소성변형과 수명에 대한 각각 해석
- Oil hole 주변의 응력 해석
- Oil hole의 fillet의 반지름 변화의 따른 해석

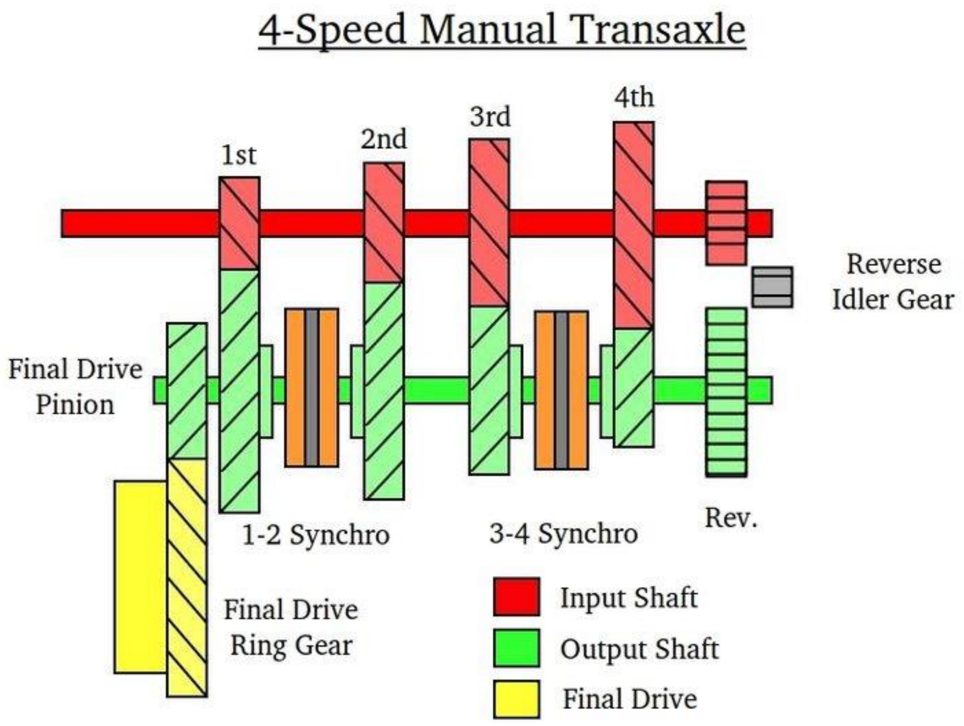
가정

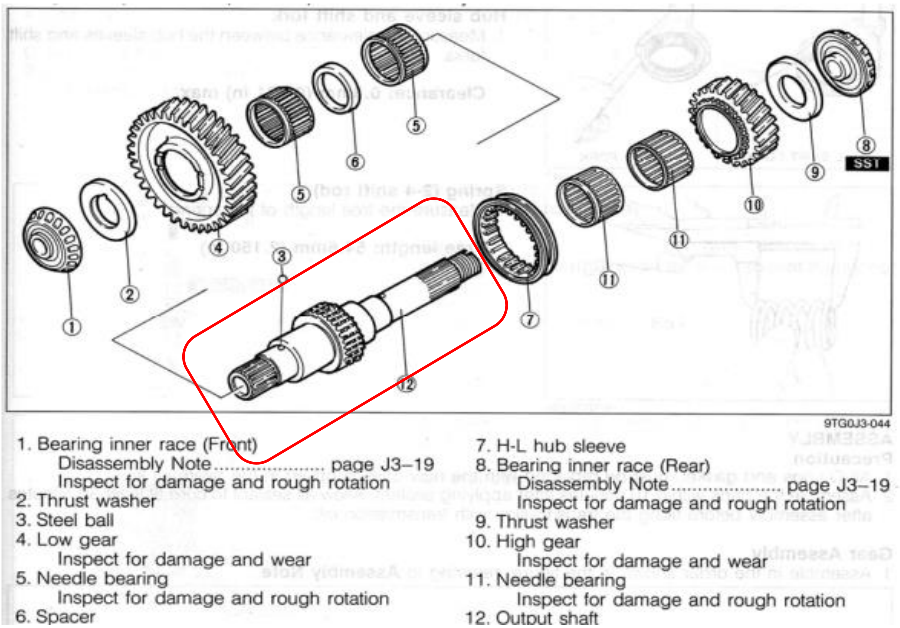
- 토크가 커서 상대적으로 작은 기어 무게나 샤프트 자중에 의한 모멘트는 무시했다.

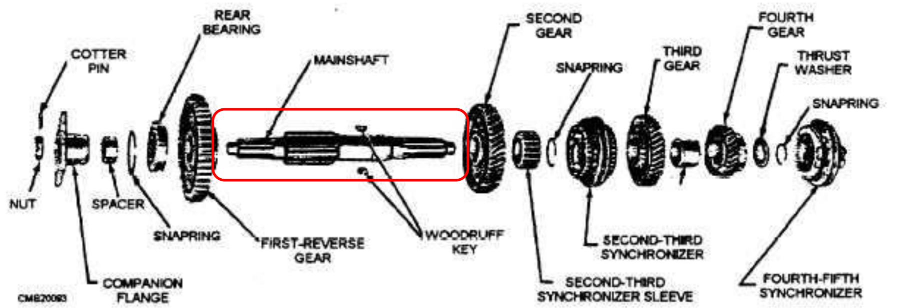
목표

- 샤프트의 안전 계수를 구하고 Minor rule을 통해 damage factor를 구한다.

기어 샤프트 모델링

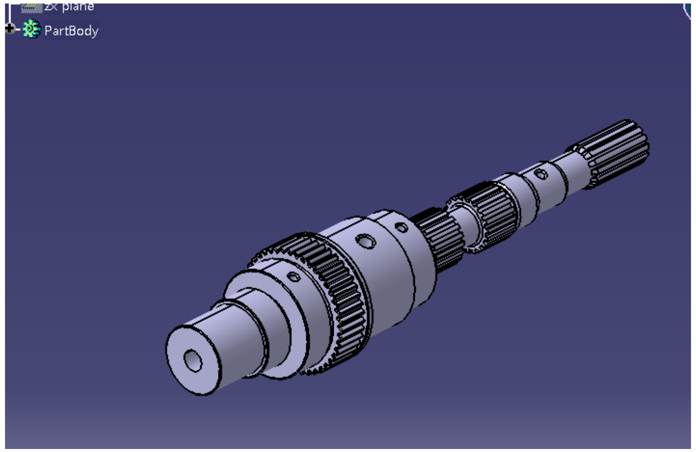

4-Speed Manual Transaxle
1st
2nd
3rd
4th
Reverse
Idler Gear
Final Drive
Pinion
1-2 Synchro
3-4 Synchro
Rev.
Final Drive
Ring Gear
Input Shaft
Output Shaft
Final Drive

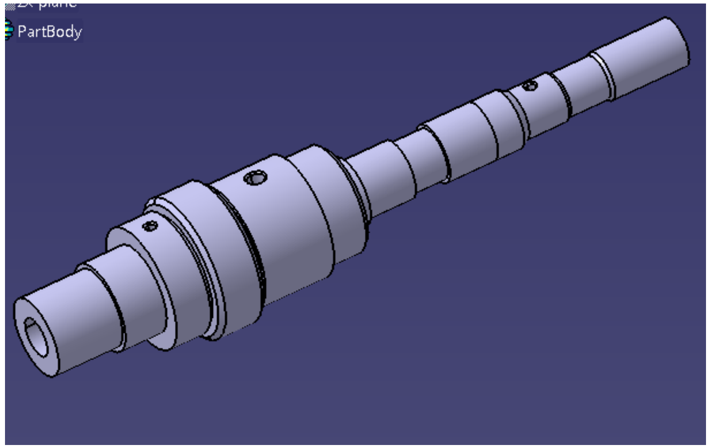

SST
9TG0J3-044
1. Bearing inner race (Front)
Disassembly Note.................... page J3–19
Inspect for damage and rough rotation
2. Thrust washer
3. Steel ball
4. Low gear
Inspect for damage and wear
5. Needle bearing
Inspect for damage and rough rotation
6. Spacer
7. H-L hub sleeve
8. Bearing inner race (Rear)
Disassembly Note.................... page J3–19
Inspect for damage and rough rotation
9. Thrust washer
10. High gear
Inspect for damage and wear
11. Needle bearing
Inspect for damage and rough rotation
12. Output shaft


REAR
BEARING
COTTER
PIN
MAINSHAFT
SECOND
GEAR
SNAPRING
THIRD
GEAR
FOURTH
GEAR
THRUST
WASHER
SNAPRING
NUT
SPACER
SNAPRING
FIRST-REVERSE
GEAR
WOODRUFF
KEY
SECOND-THIRD
SYNCHRONIZER
SECOND-THIRD
SYNCHRONIZER SLEEVE
FOURTH-FIFTH
SYNCHRONIZER
COMPANION
FLANGE
CMB20093

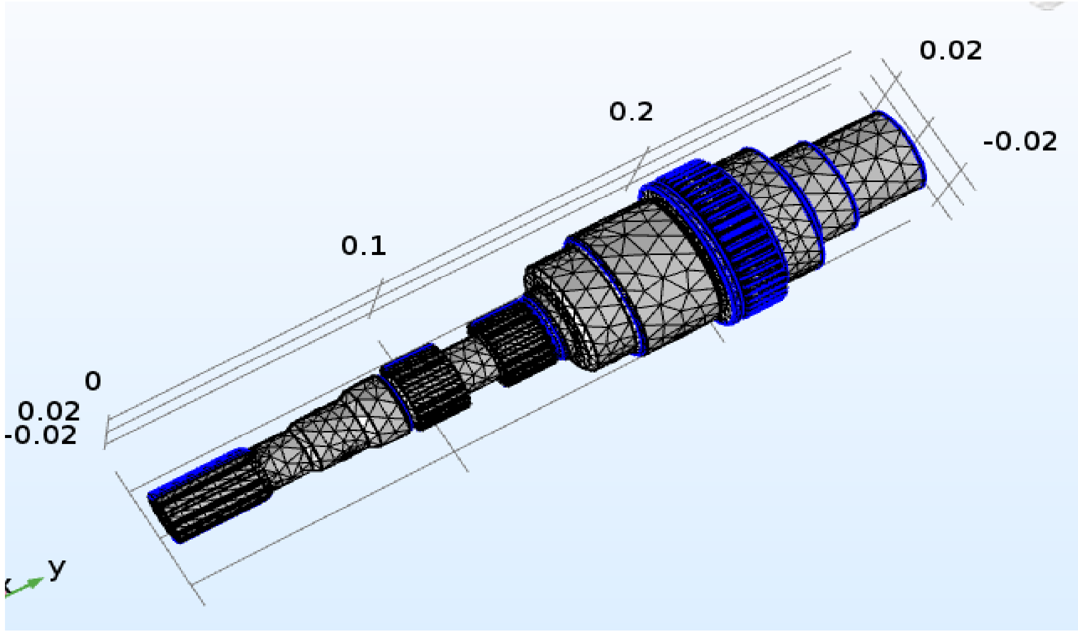
모델링 단순화 과정

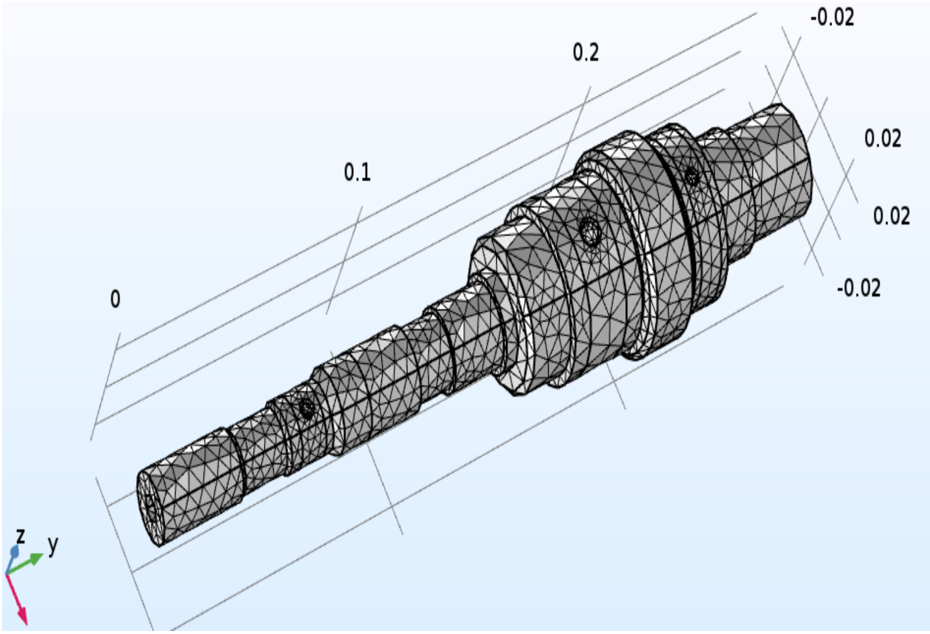

BW4411 Main Shaft
info@CobraTransmission.com
1-800-293-1848
U4411-678
www.cobratransmission.com


PartBody


PartBody

COMSOL(모델링 단순화 후 Mesh)





Free Tetrahedral 2
- Warning 1
- Warning 2

Warning

Face is (or has a narrow region that is) much smaller than the specified minimum element size.

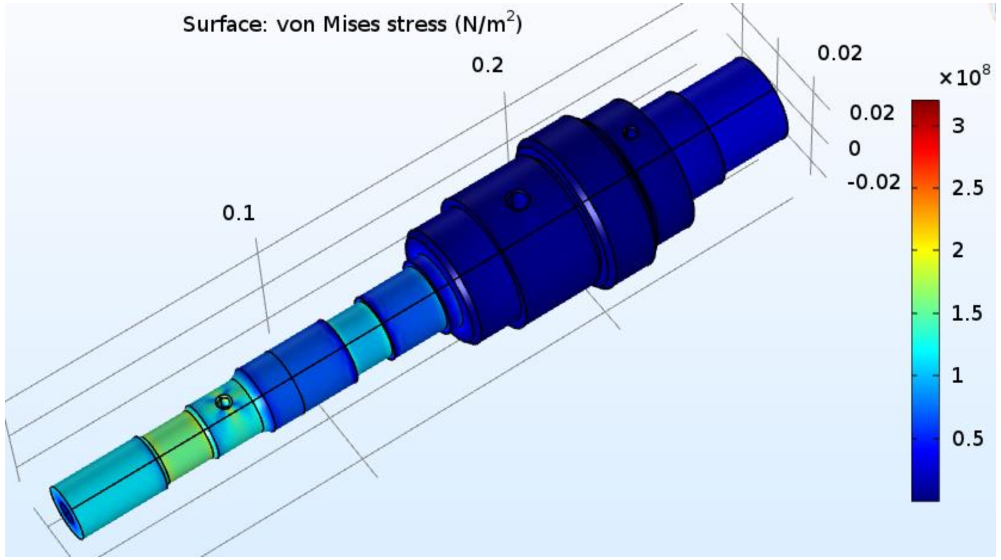
Warning

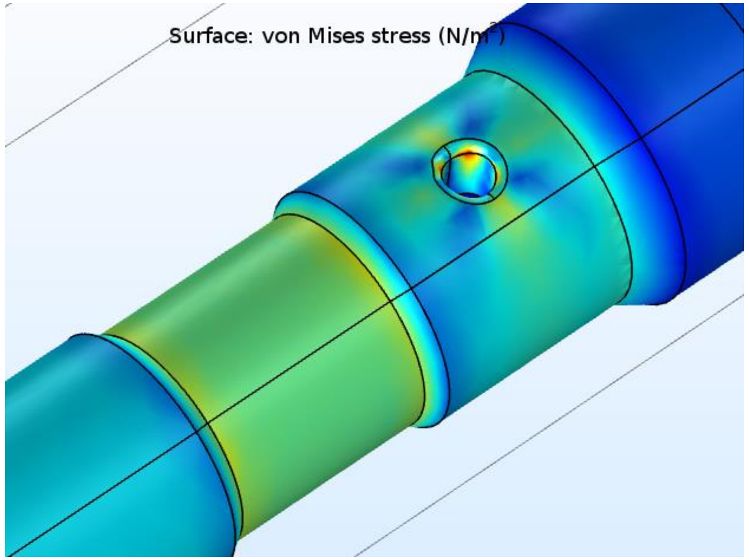
Face is (or has a narrow region that is) much smaller than the specified minimum element size.

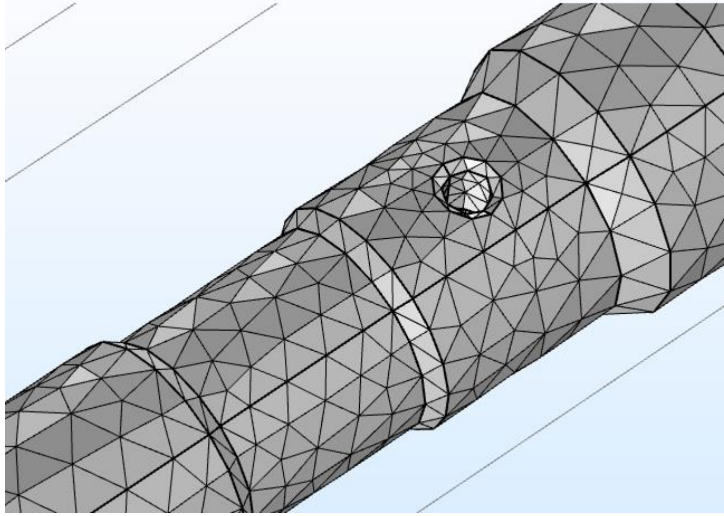
Complete mesh consists of 14054 domain elements,

5759 boundary elements, and 1473 edge elements.

Fine

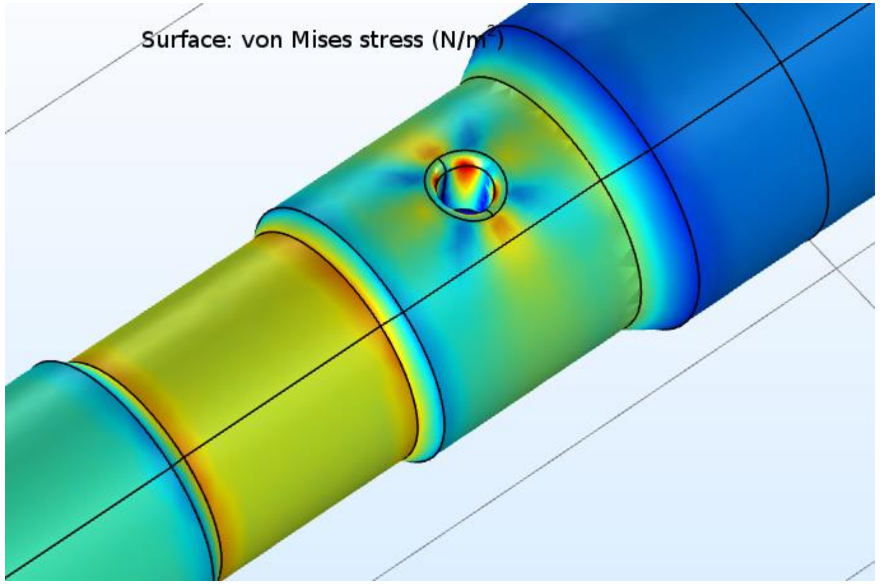






Used linear geometry shape in 19 mesh elements to avoid inverted curved elements.
Number of degrees of freedom solved for: 121813.
Solution time (Study 1): 18 s.

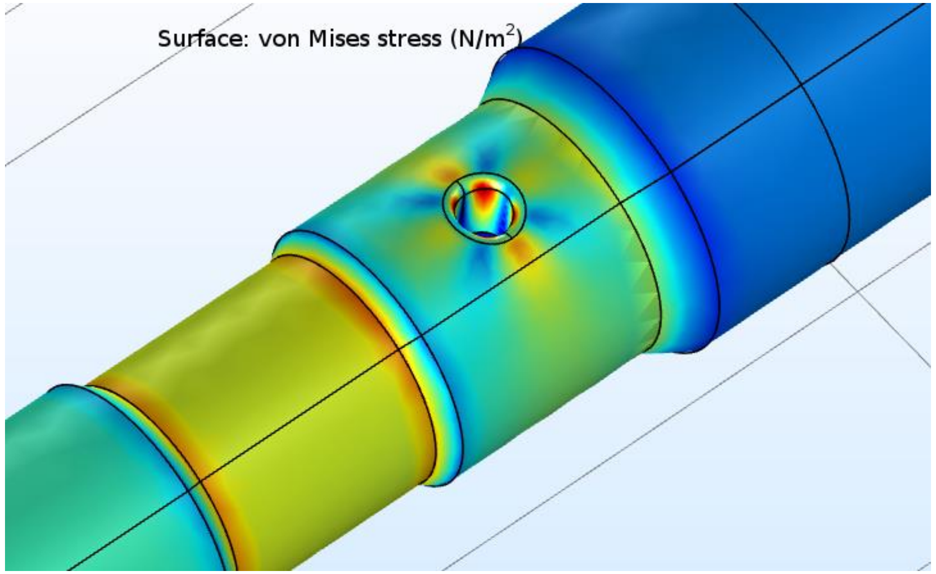
Finer



Used linear geometry shape in 28 mesh elements to avoid inverted curved elements.
Number of degrees of freedom solved for: 298105.
Solution time (Study 1): 57 s.

57초의 시간이 걸린다.

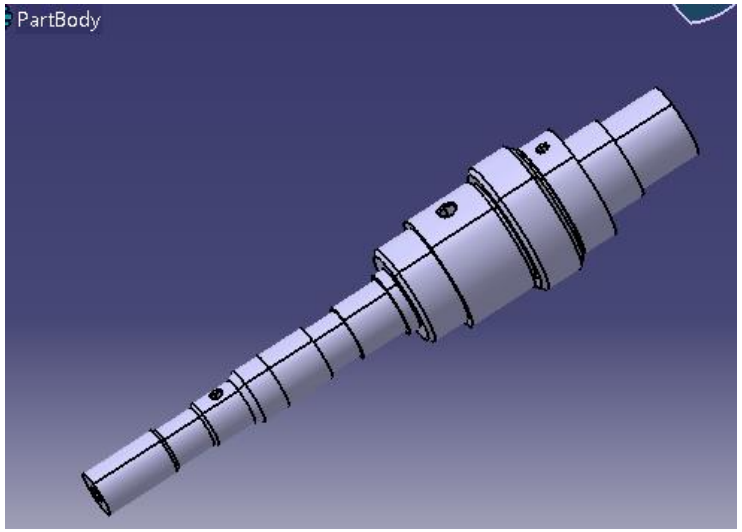
Extra Fine

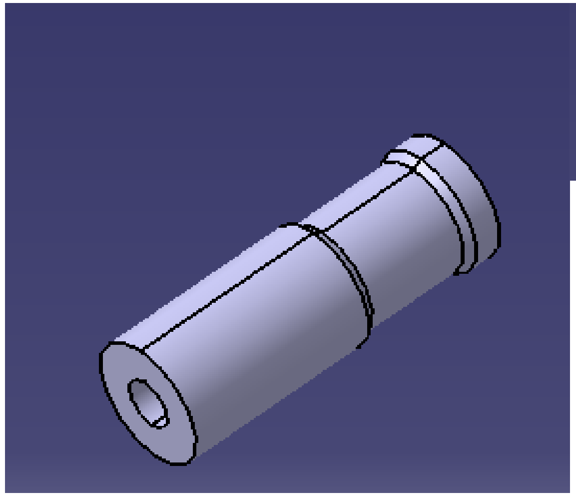


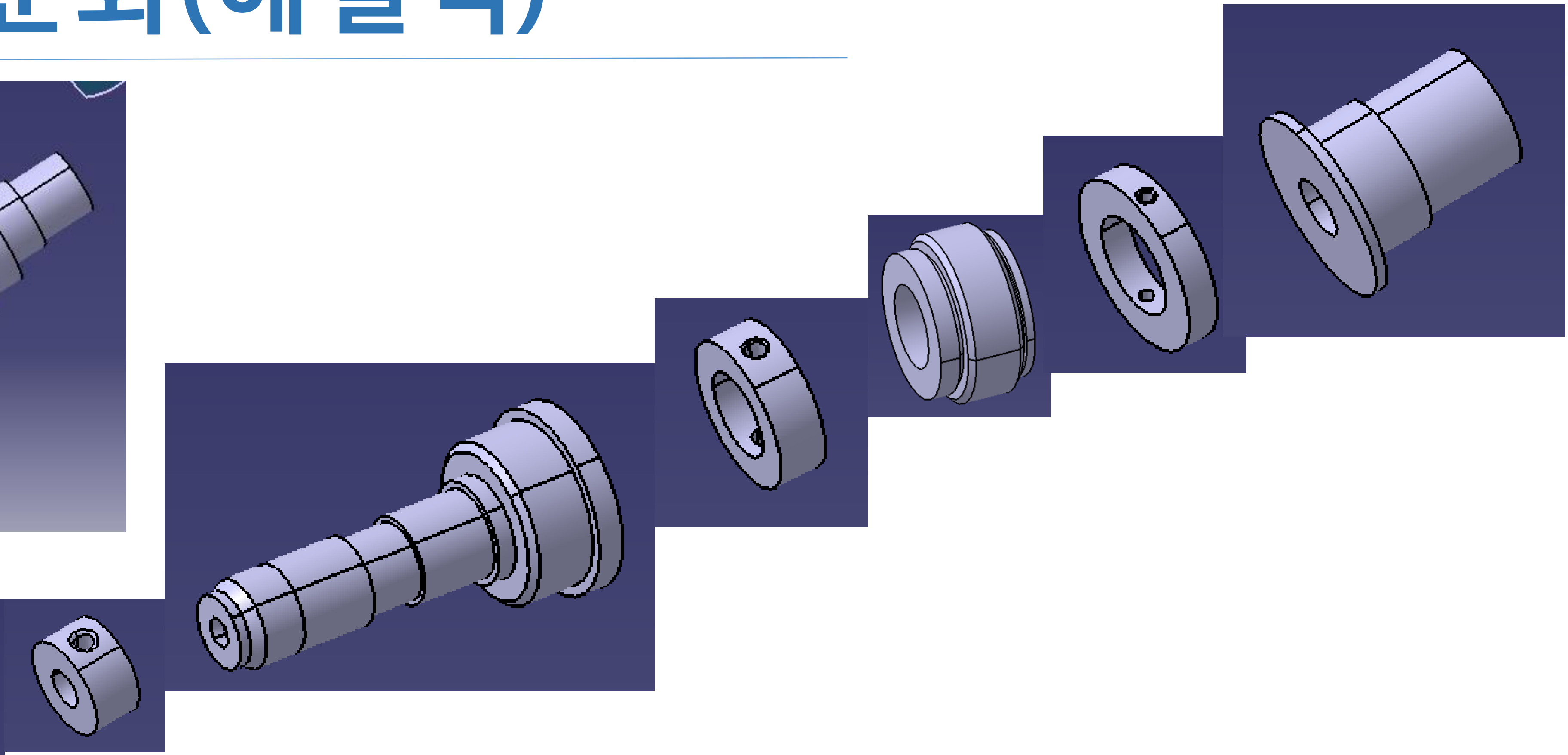
Complete mesh consists of 160668 domain elements, 27206 boundary elements, and 3134 edge elements.
Number of degrees of freedom solved for: 724318.
Solution time (Study 1): 544 s. (9 minutes, 4 seconds)

9분 4초의 시간이 걸린다.

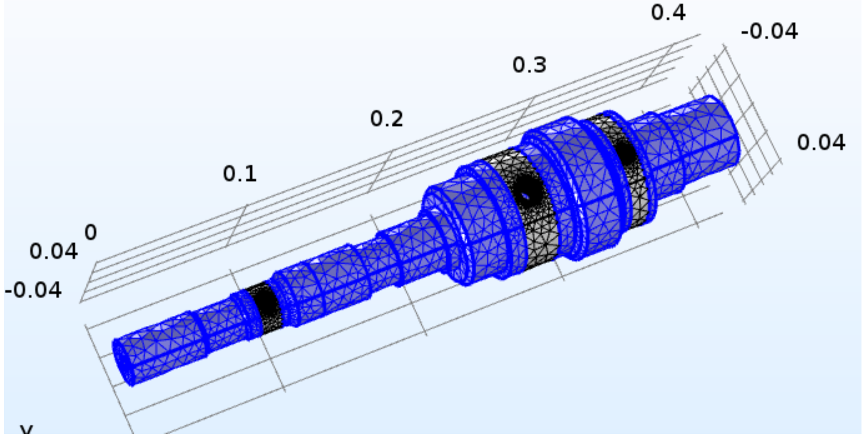
모델링 세분화(해결책)

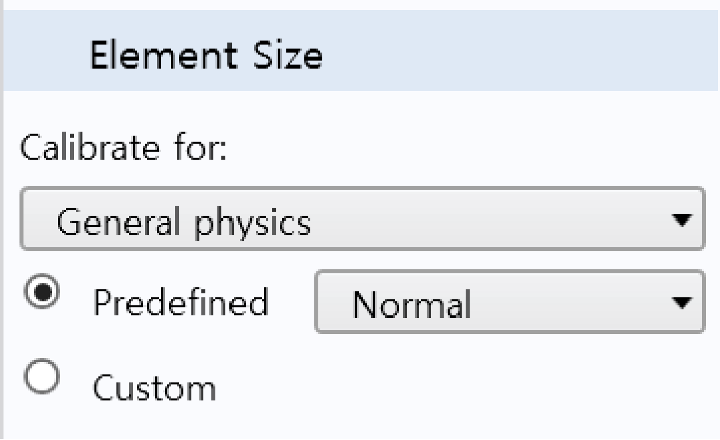


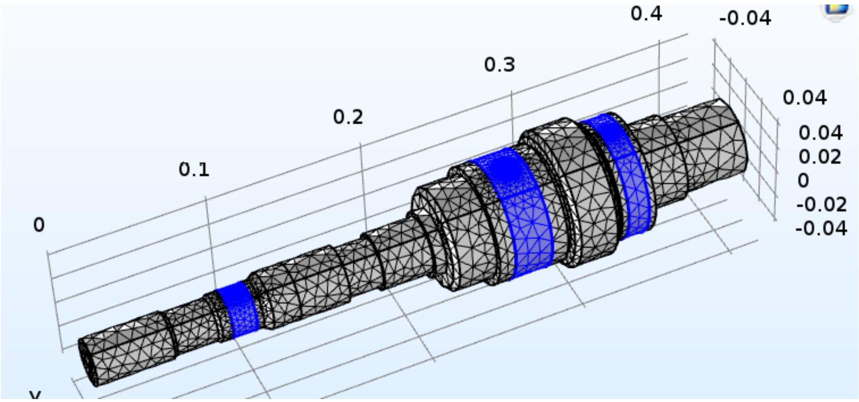


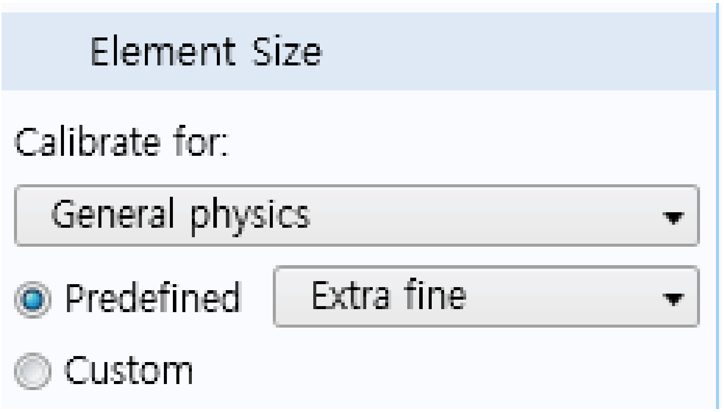


모델링 세분화를 통한 COMSOL(Mesh)

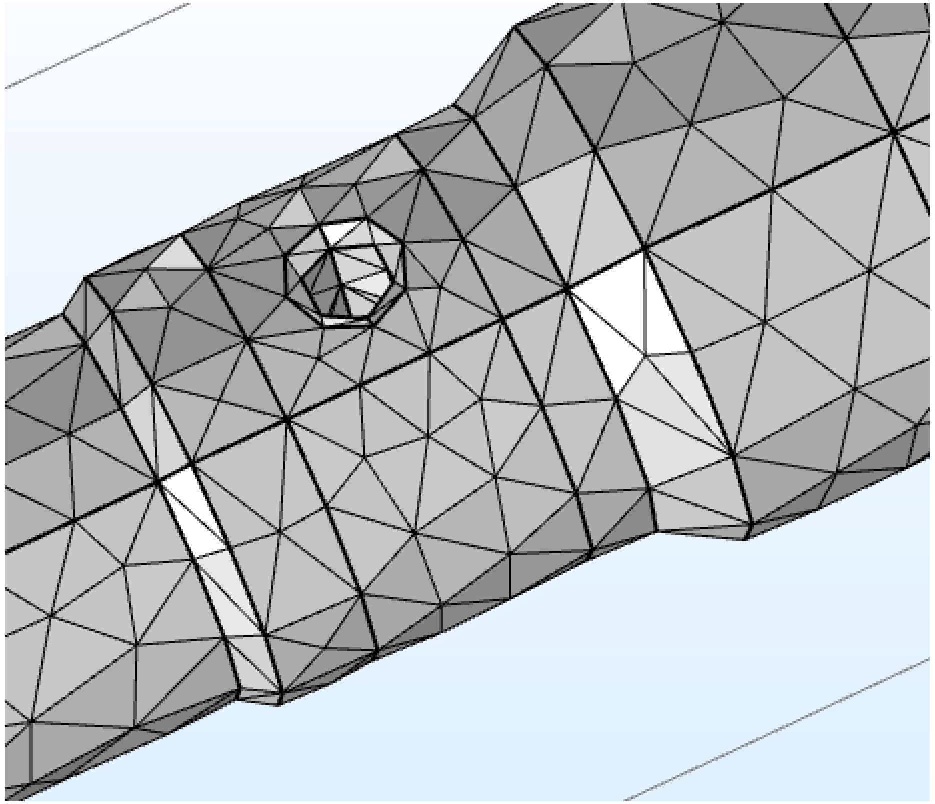


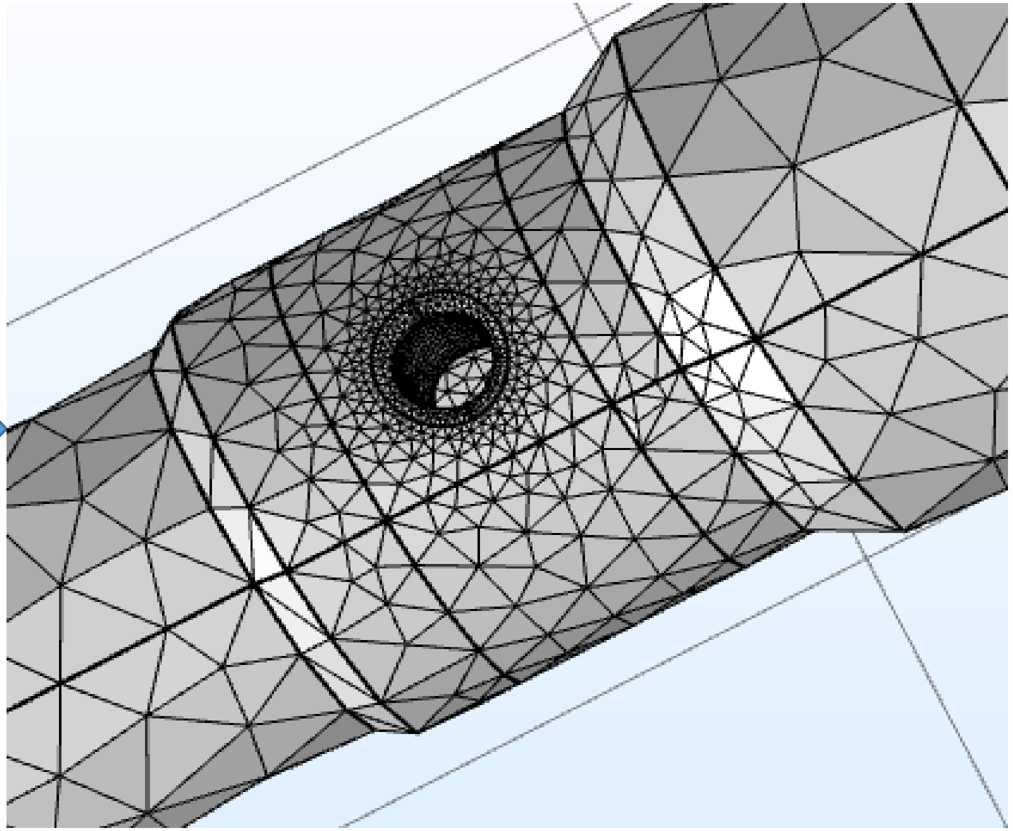






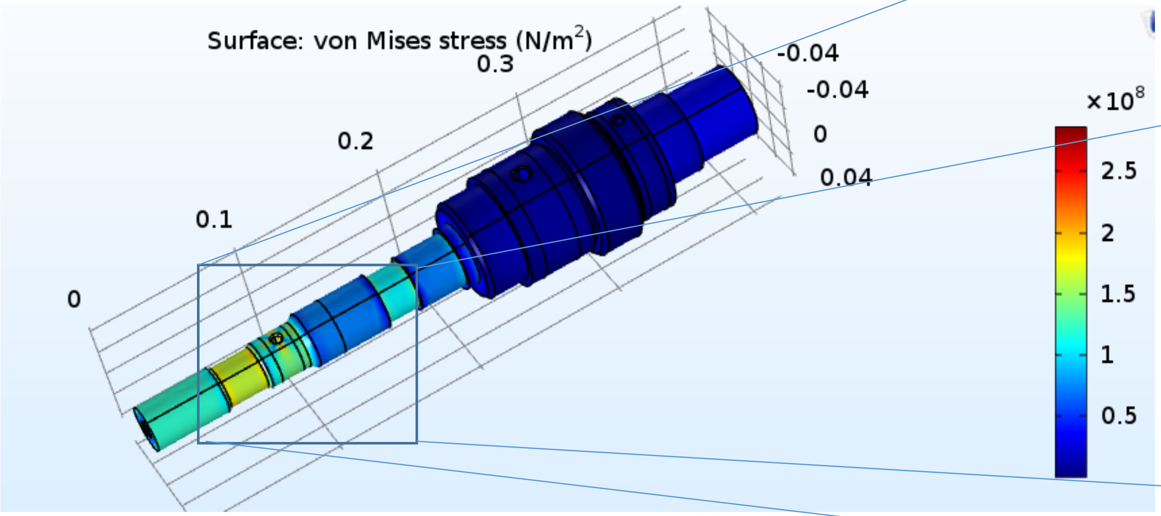
Normal->Extra fine

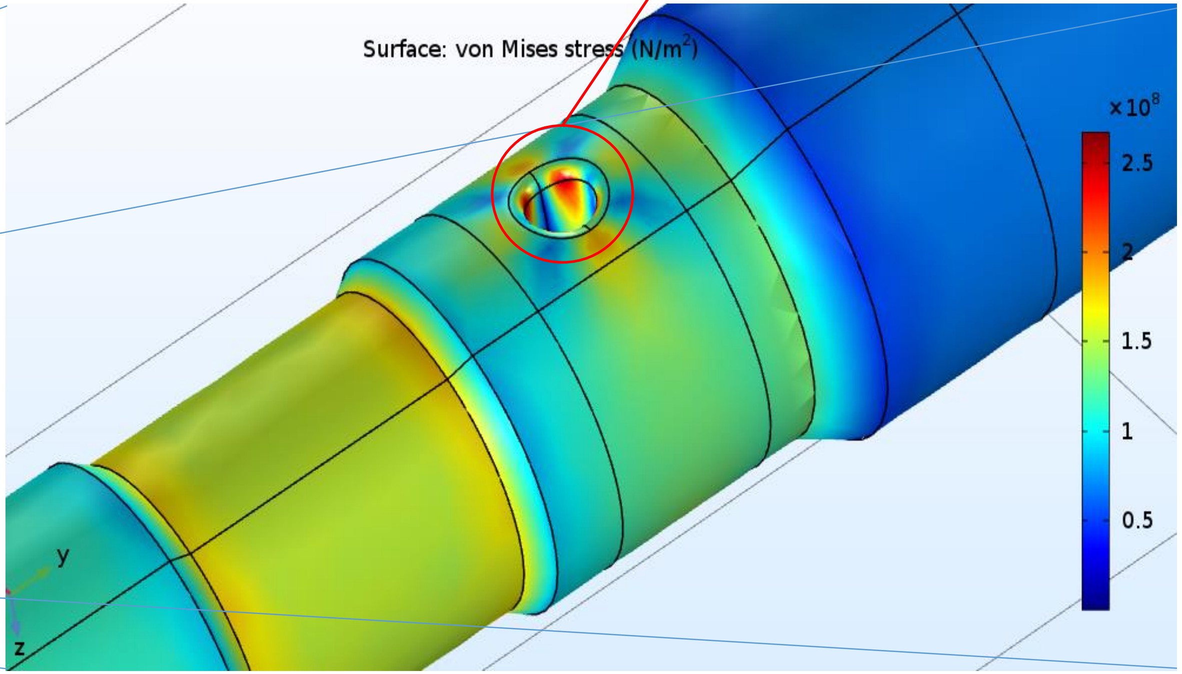




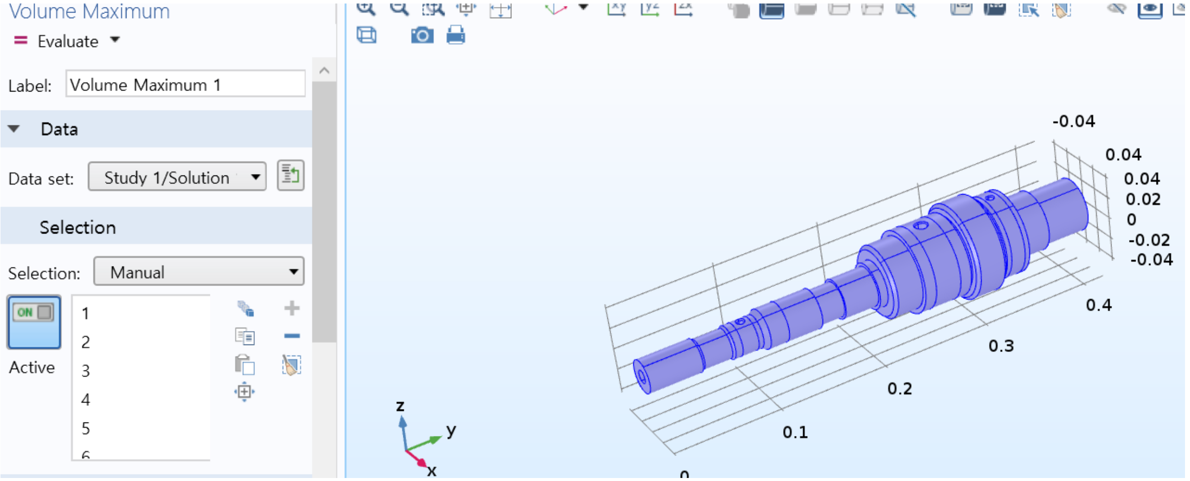
최대 응력 확인(Max torque)

최대 응력 발생 지점





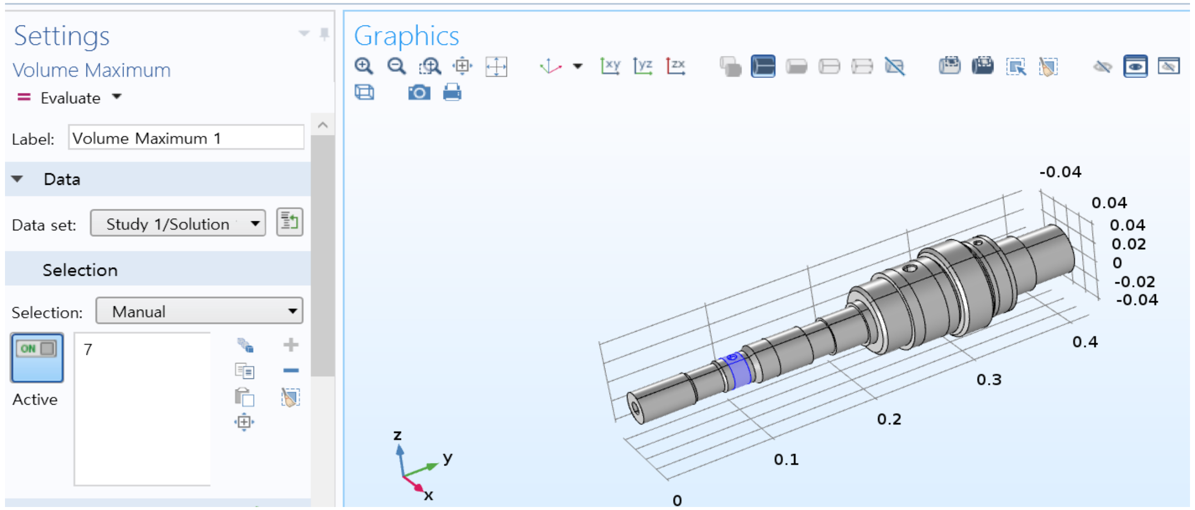
최대스트레스지역이 첫 번째 홀인지 확인



von Mises stress (N/m^2)
2.8915E8

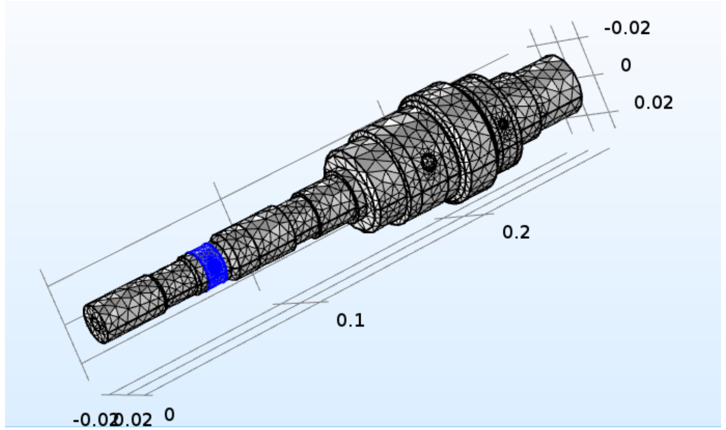
Derived Values

Volume Maximum



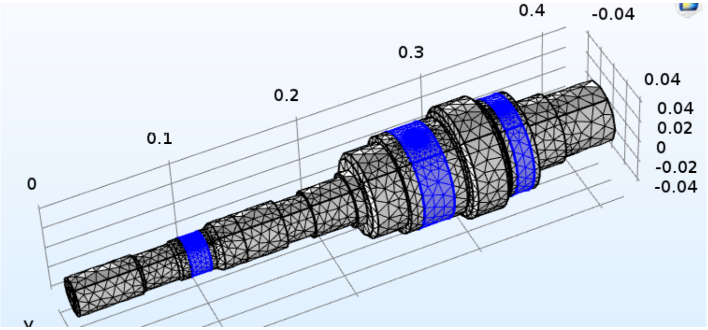
von Mises stress (N/m^2)
2.8915E8

스트레스 비교



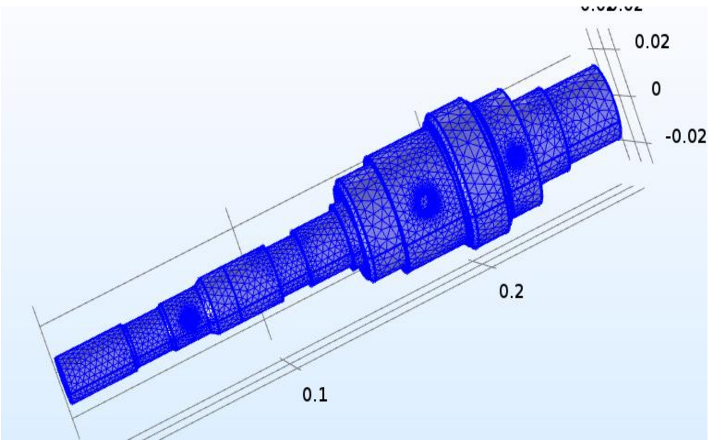
von Mises stress (N/m^2)
2.8915E8

Normal+extra fine
1 domain



) von Mises stress (N/m^2)
2.8912E8

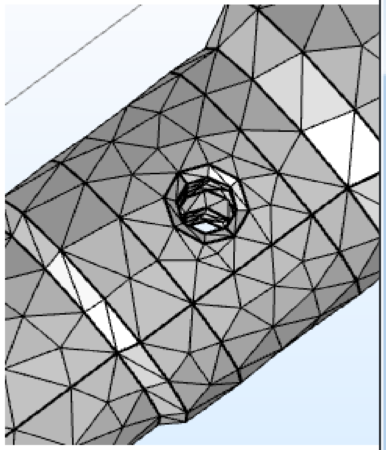
Normal+extra fine
3개



von Mises stress (N/m^2)
2.8910E8

all
extra fine

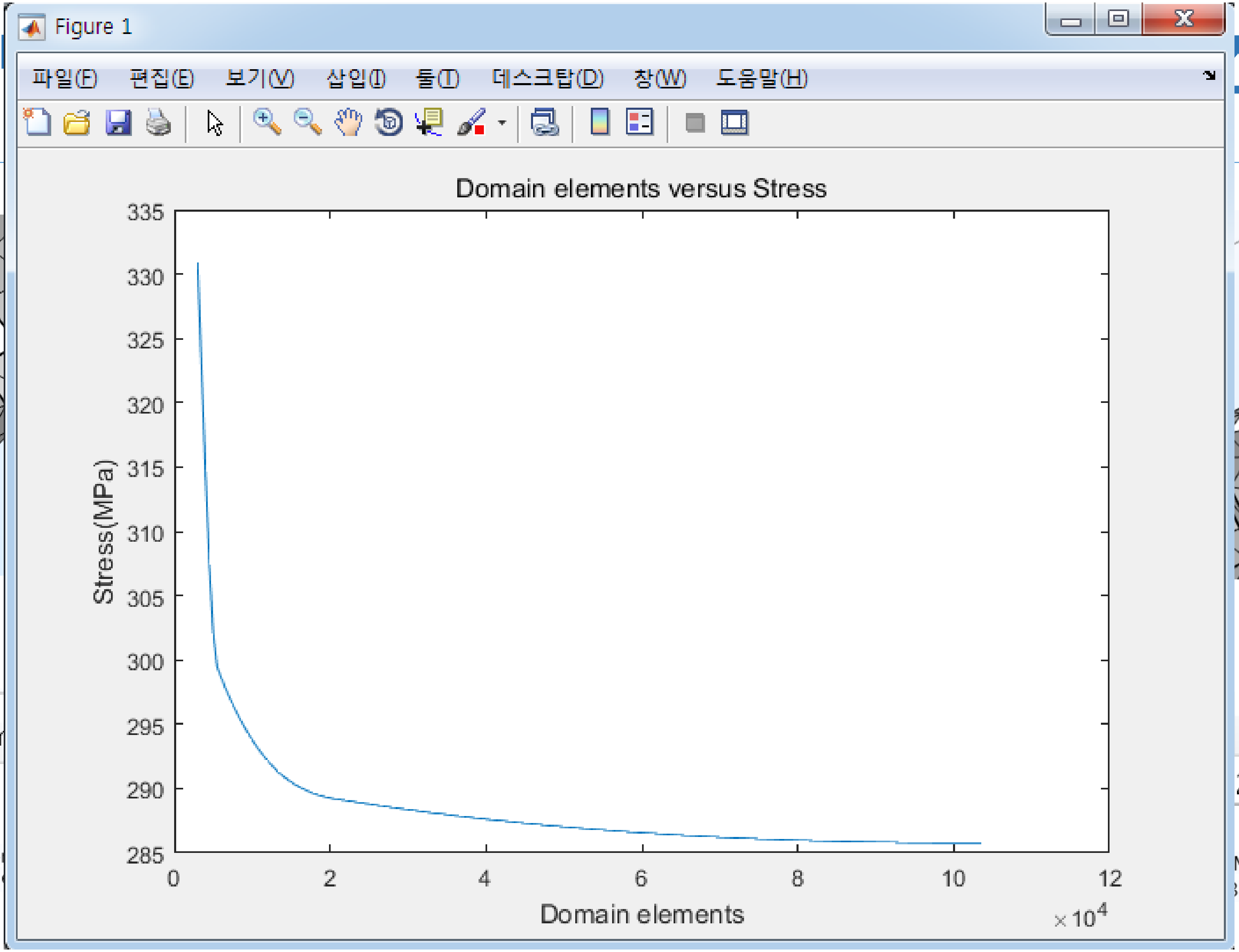
오일구 … 스 비교

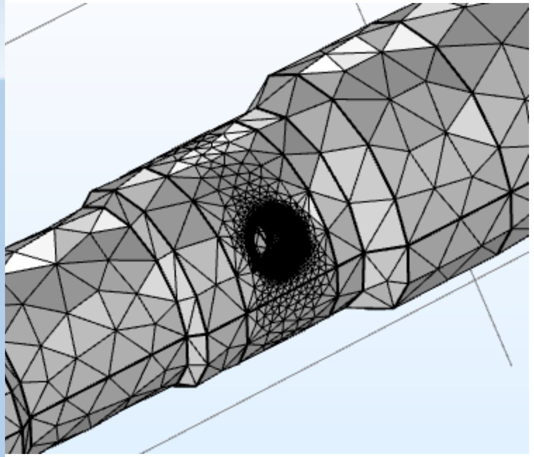


Fine 일 때

von Mises stress (N/m
3.3527E8

Mesh consists of 2712 domain ele
966 boundary elements, and 172 edge





Extremely fine 일 때

von Mises stress (N/m^2)
2.8578E8

Mesh consists of 103658 domain elements,
8 boundary elements, and 816 edge elements.

점점 수렴

AISI 1050 Steel, water quenched from 830°C

Physical Properties	Metric	English	Comments
Density	7.87 g/cc	0.284 lb/in^3	Typical for steels.

Mechanical Properties	Metric	English	Comments
Hardness, Brinell	235	235	
Hardness, Knoop	259	259	Converted from Brinell hardness.
Hardness, Rockwell B	97	97	Converted from Brinell hardness.
Hardness, Rockwell C	21	21	Converted from Brinell hardness.
Hardness, Vickers	247	247	Converted from Brinell hardness.
Tensile Strength, Ultimate	808 MPa	117000 psi	
Tensile Strength, Yield	543 MPa	78800 psi	
Elongation at Break	23 %	23 %	in 50 mm
Reduction of Area	61 %	61 %	
Modulus of Elasticity	200 GPa	29000 ksi	Typical for steel
Bulk Modulus	160 GPa	23200 ksi	Typical for steels.
Poissons Ratio	0.29	0.29	Typical For Steel
Shear Modulus	80.0 GPa	11600 ksi	Typical for steels.
Izod Impact	18.0 J	13.3 ft-lb	annealed at 790°C (1450°F)
	27.0 J	19.9 ft-lb	normalized at 900°C (1650°F)
	31.0 J	22.9 ft-lb	as rolled

Electrical Properties	Metric	English	Comments
Electrical Resistivity	0.0000163 ohm-cm @Temperature 0.000 °C	0.0000163 ohm-cm @Temperature 32.0 °F	annealed specimen
	0.0000224 ohm-cm @Temperature 100 °C	0.0000224 ohm-cm @Temperature 212 °F	annealed specimen
	0.0000300 ohm-cm @Temperature 200 °C	0.0000300 ohm-cm @Temperature 392 °F	annealed specimen

Thermal Properties	Metric	English	Comments
CTE, linear	11.5 µm/m-°C @Temperature 20.0 °C	6.39 µin/in-°F @Temperature 68.0 °F	Typical steel
	12.2 µm/m-°C @Temperature 0.000 - 300 °C	6.78 µin/in-°F @Temperature 32.0 - 572 °F	Typical for steel
	13.9 µm/m-°C @Temperature 0.000 - 500 °C	7.72 µin/in-°F @Temperature 32.0 - 932 °F	Typical for steel
Specific Heat Capacity	0.486 J/g-°C @Temperature >=100 °C	0.116 BTU/lb-°F @Temperature >=212 °F	annealed
Thermal Conductivity	51.9 W/m-K	360 BTU-in/hr-ft^2-°F	Typical steel

Component Elements Properties	Metric	English	Comments
Carbon, C	0.47 - 0.55 %	0.47 - 0.55 %	
Iron, Fe	98.46 - 98.92 %	98.46 - 98.92 %	As remainder
Manganese, Mn	0.60 - 0.90 %	0.60 - 0.90 %	
Phosphorous, P	<= 0.040 %	<= 0.040 %	
Sulfur, S	<= 0.050 %	<= 0.050 %	

Specify:
Young's modulus and Poisson's ratio

$\mathbf{C} = \mathbf{C}(E, \nu)$

Young's modulus:
E User defined
200e9 Pa

Poisson's ratio:
ν User defined
0.29 1

Density:
ρ User defined
7870 kg/m^3

출처- http://www.matweb.com/search/DataSheet.aspx?MatGUID=e59e1475a6984fe7bd04dae894be755c

Von Mises Stress

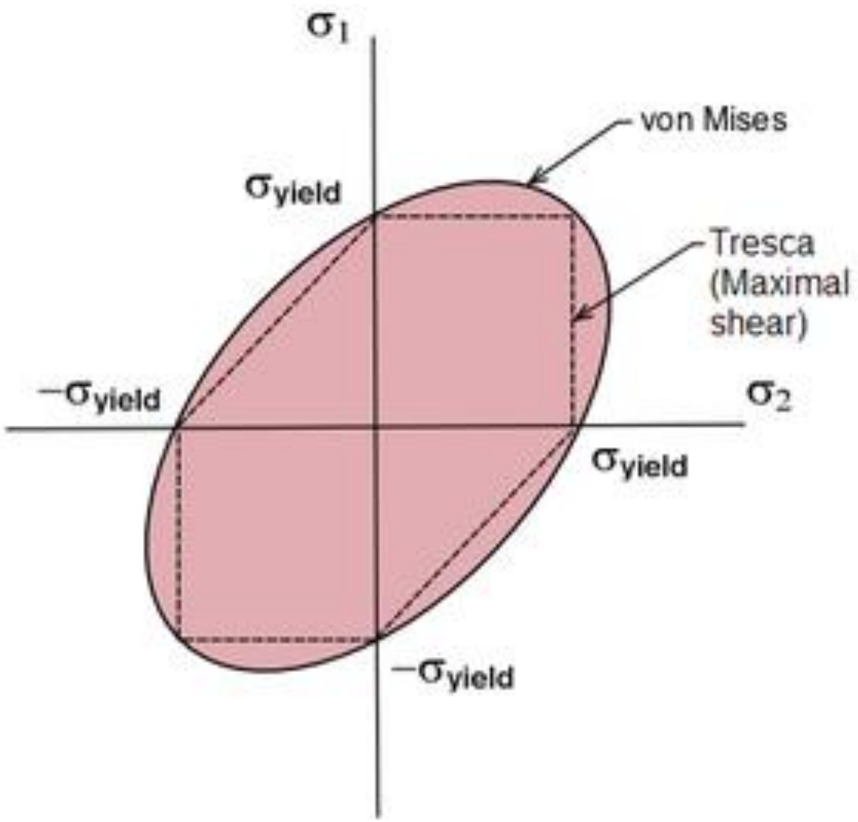
물체의 파괴를 가장 정확하게 예측하는 기준이다.

$$\sigma' \equiv \sqrt{\sigma_1^2 + \sigma_2^2 + \sigma_3^2 - \sigma_1\sigma_2 - \sigma_2\sigma_3 - \sigma_3\sigma_1}$$

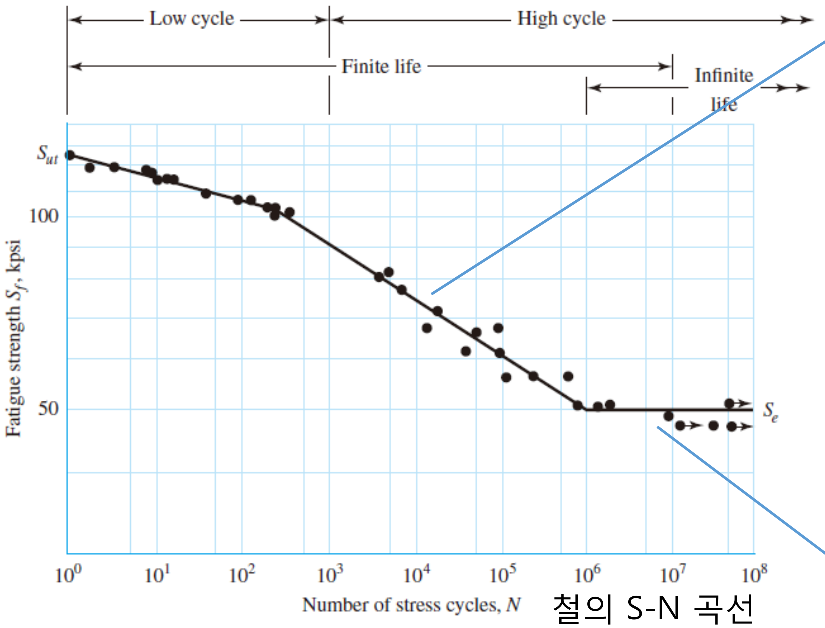
$$= \frac{1}{\sqrt{2}}\sqrt{(\sigma_x - \sigma_y)^2 + (\sigma_y - \sigma_z)^2 + (\sigma_z - \sigma_x)^2 + 6(\tau_{xy}^2 + \tau_{xz}^2 + \tau_{yz}^2)}$$

$$\sigma' = \frac{S_y}{n} \quad \rightarrow \quad n = \frac{S_y}{\sigma'} = \frac{543MPa}{289MPa} = \boxed{1.88}$$

의 안전 계수를 갖는다.



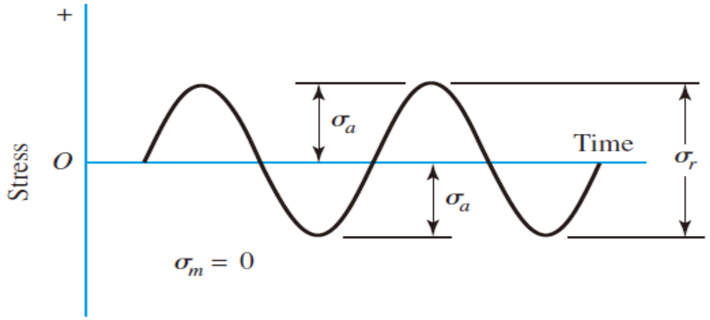
피로 수명



철의 S-N 곡선

$10^3 \sim 10^6$cycle (High cycle) 일 때

$$a = \frac{(f\,S_{ut})^2}{S_e} \quad b = -\frac{1}{3}\log\left(\frac{f\,S_{ut}}{S_e}\right)$$ 를 구하고



$$N = \left(\frac{\sigma_{\text{rev}}}{a}\right)^{1/b}$$

대입하여 수명을 구할 수 있다.

10^6cycle 이상 일 때

N = ∞ (즉, 무한 수명을 가진다.)

피로도 계산

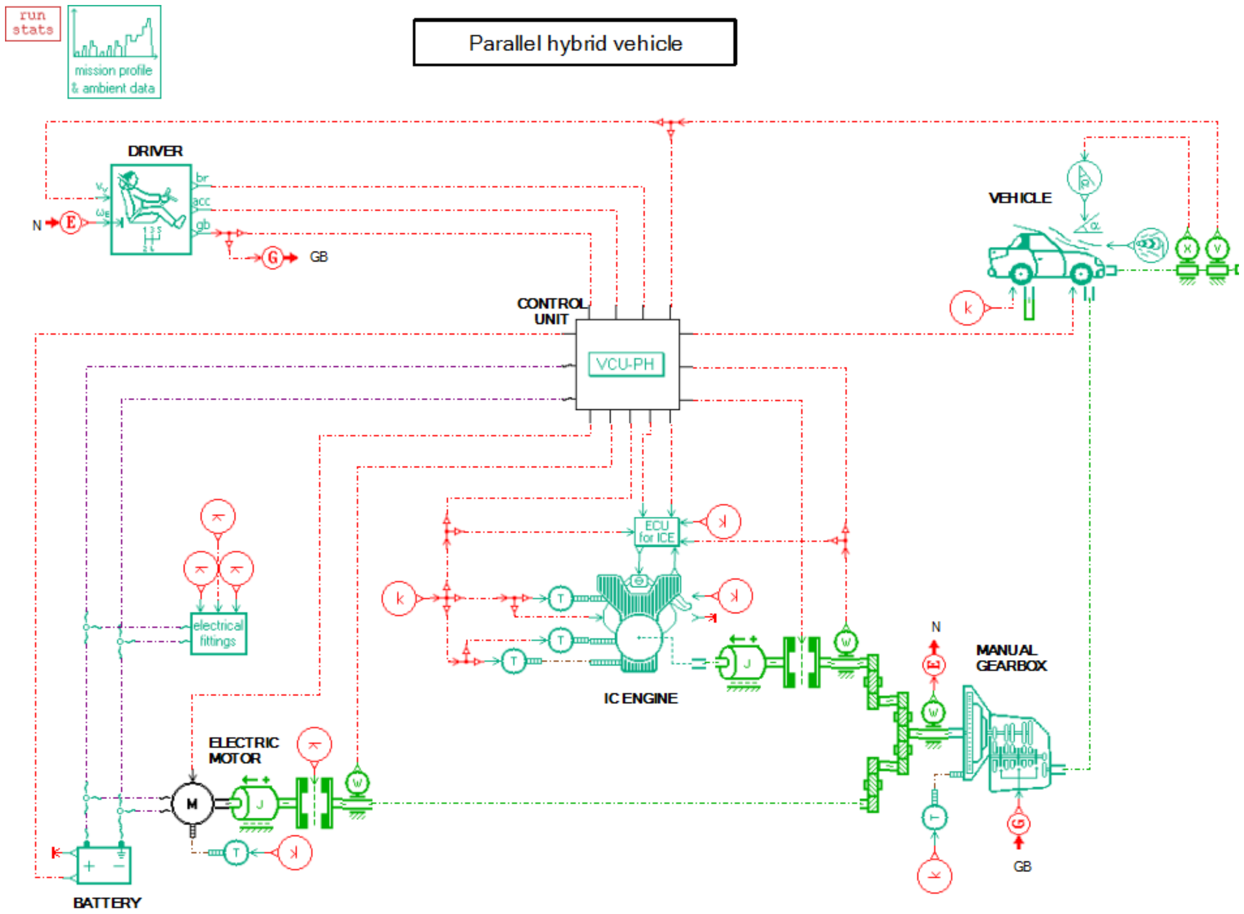
Define *D* as the accumulated damage,

$$D = \sum \frac{n_i}{N_i}$$

When D = c = 1, failure ensures

무한 수명인 싸이클은 $\frac{n_i}{N_i} = \frac{a}{\infty} = 0$ 이므로 고려하지 않는다.

Amesim 소스



운행 중에 Shaft에 가해지는 토크를 알기 위해 Amesim의 ‘Parallel hybrid vehicle’ 소스를 활용하였다.

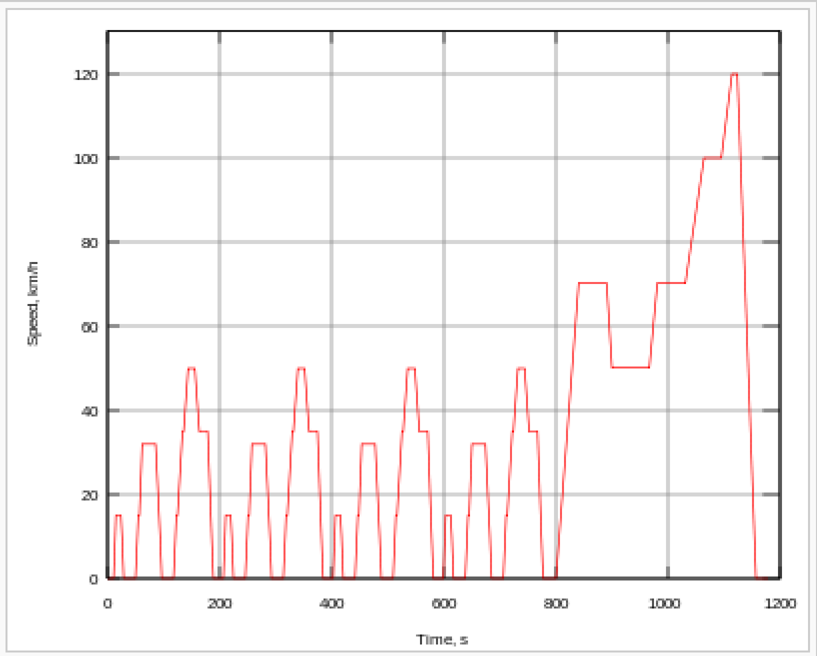
Model 설정

구분	현대 아이오닉
전장(mm)	4470
전폭(mm)	1820
전고(mm)	1450
축간거리	2700
엔진	카파 1.6 GDi
모터	32kw(영구자석형)
배터리(kwh)	1.56 (리튬이온 폴리머)
변속기	6단DCT
후륜 서스펜션	멀티링크
초고장력강판비율	53%
에어백	7개
연비절약기술	ECO-DAS
공차중량(kg)	1380kg(15인치)

구분			기어비							
차종	변속기	엔진	1단	2단	3단	4단	5단	6단	후진	종감속비
아이오닉 하이브리드	D6KF1	1.6 GDi	3.667	2.217	1.371	0.930	0.956	0.767	5.531	1-4 : 4.188 5-6-R : 3.045

vehicle linear veloci···	0 m/s
vehicle linear displa···	0 m
vehicle index	1
vehicle configuration	road
longitudinal slip config···	without slip
total vehicle mass	1.38 tonne
mass distribution (60%···	50 %
wheel inertia	0.75 kgm**2
tire width	185 mm
tire height	60 %
wheel rim diameter	15 in
expression for wheel d···	Rw
aerodynamic and r···	
brake characteristics	
transmission gear ···	
transmission gear r···	3.667 null
transmission gear r···	2.217 null
transmission gear r···	1.371 null
transmission gear r···	0.93 null
transmission gear r···	0.956 null
transmission gear r···	0.767 null
transmission gear ···	

NEDC

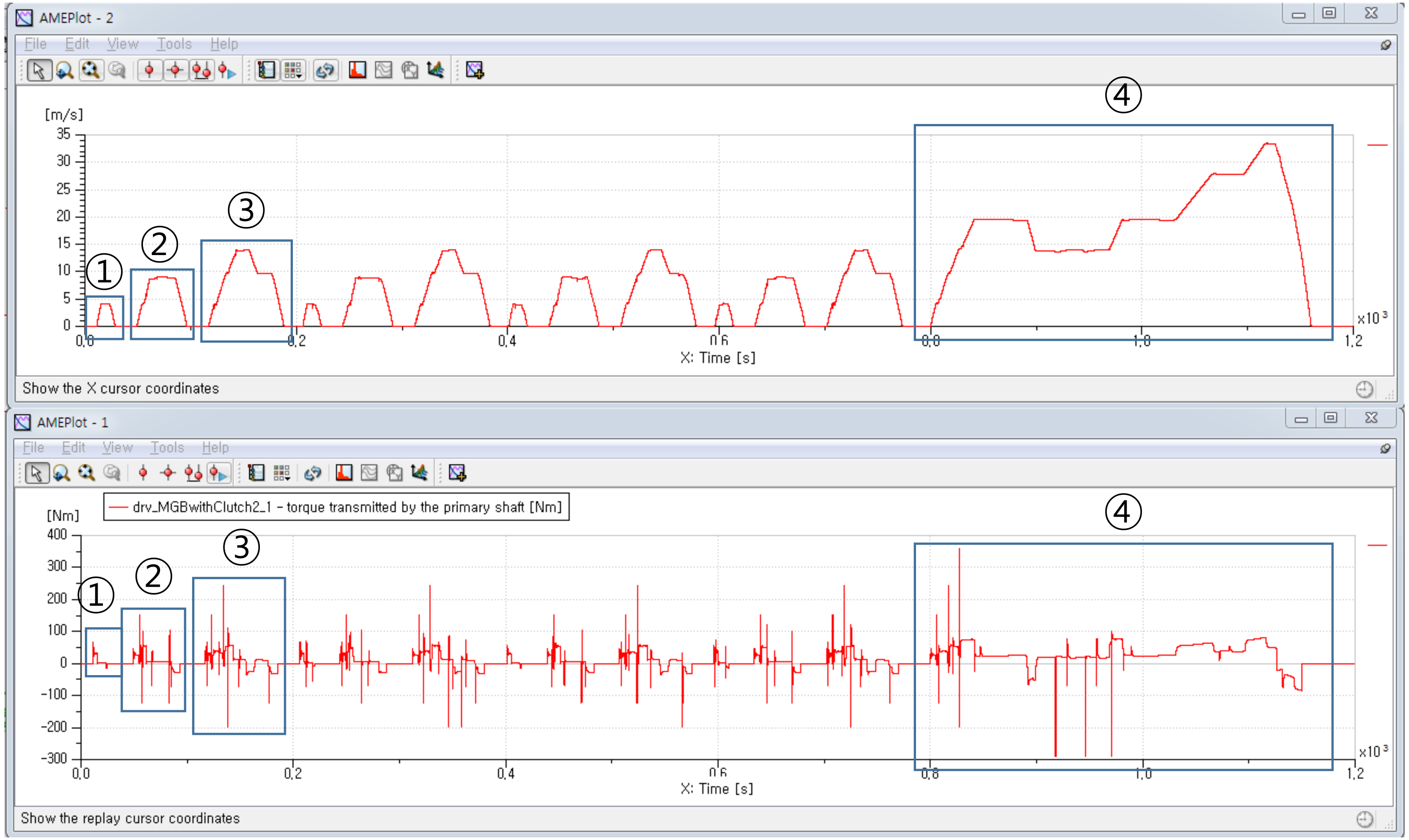


NEDC는 New European Driving Cycle 의 줄임말로 유럽에서 사용하는 연비 측정 방식을 말합니다. ECE15(시가지 주행)과 EUDC(고속주행)으로 구성되어 있습니다.

시가지 주행 모드 인 ECE15는 4회 반복
주행거리: 1013×4=4052km
소요시간: 195×4=780 sec
평균속도: 18.7km/h
최대속도: 50km/h

고속 주행 모드인 EUDC(Extra Urban Driving Cycle)는 1회
주행거리: 6955×1=6955km
소요시간: 400×1=400 sec
평균속도: 62.6km/h
최대속도: 120km/h

Mode 나누기

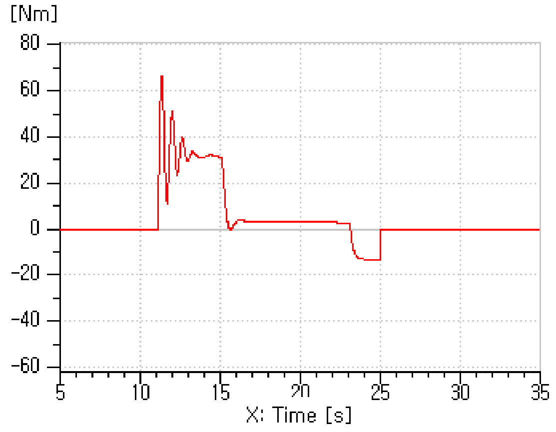


차량의 속도 :
시가지 : (①+②+③) x 4회
고속 : ④ x 1회

Shaft에 가해지는 토크

피로 하중 분석

Ex)



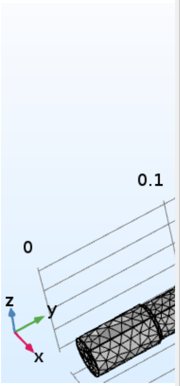
①번 토크를 확대하여

1) Tmax = 65Nm Tmin = 0Nm
2) Tmax = 3Nm Tmin = -14Nm
이렇게 2개의 피로 하중을 찾는다.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
1	mode	1																					
2	Tmax	65	3																				
3	Tmin	0	-14																				
4	mode	2																					
5	Tmax	45	150	55	120	70	-130	10															
6	Tmin	0	0	0	105	-40	100	-75															
7	mode	3																					
8	Tmax	50	70	35	150	40	65	245	50	110	45	10	0										
9	Tmin	-70	0	0	-20	-40	10	10	-10	-195	-75	-35	-120										
10	mode	4																					
11	Tmax	45	150	20	60	245	60	360	30	70	50	20	20	75	20	80	65	100	50	65	50	70	0
12	Tmin	0	0	-120	0	-75	-30	25	-290	-20	25	-50	-290	-70	-290	-70	-290	-25	-25	10	30	50	-80

같은 방법으로 mode ①,②,③,④
모두 조사하여 엑셀 파일로 정리

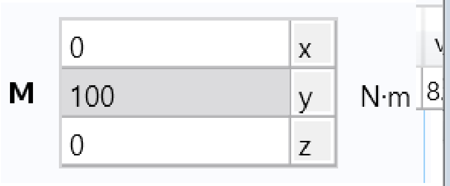
Torque & Von Mises stress의 관계

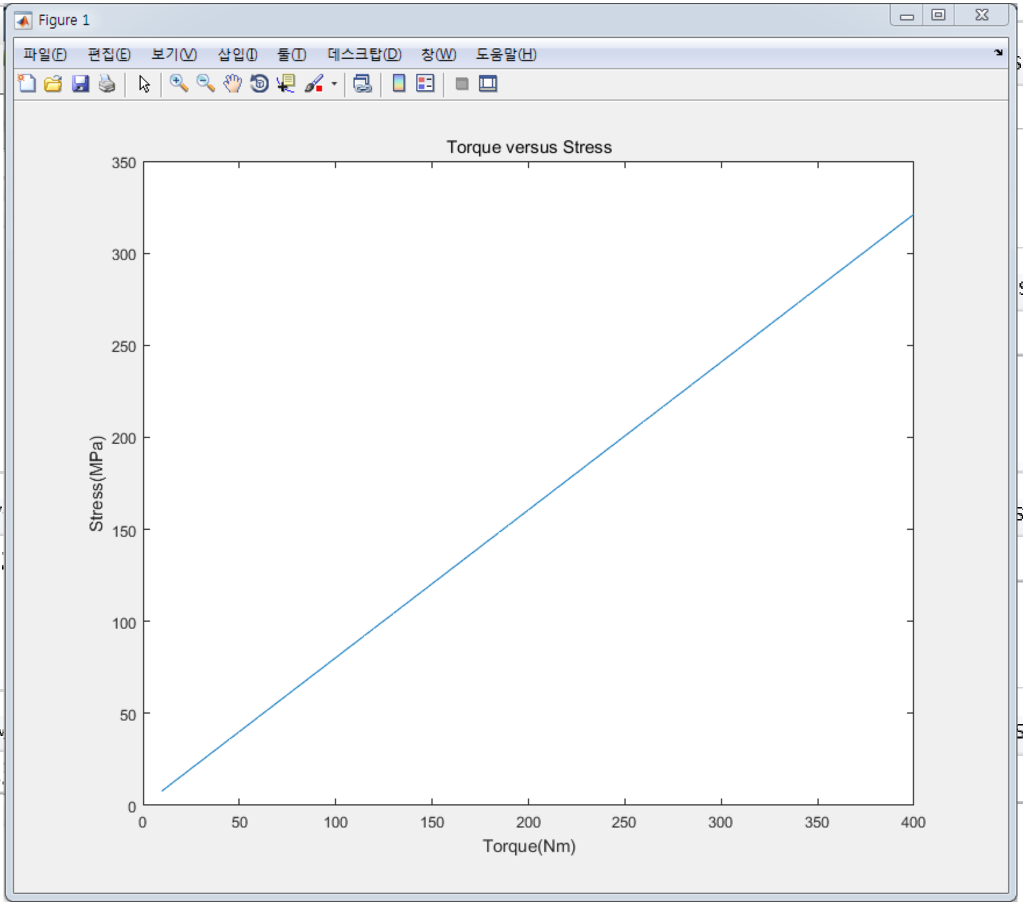


편집기 - C:₩Users₩Administrator₩Desktop₩Untitled.m

Untitled.m

```
torque = [10,20,40,100,200,300,360,400];
stress = [8.030, 1.606*10, 3.212*10, 8.031*10 ...
          1.606*10^2, 2.409*10^2, 2.892*10^2, 3.212*10^2];
torque_input = [0:5:400];
stress_output = interp1(torque,stress,torque_input);
plot(torque_input,stress_output);
xlabel('Torque(Nm)');
ylabel('Stress(MPa)');
title('Torque versus Stress');
```





Matlab을 이용하여
Torque와 Von Mises stress가
선형임을 알 수 있다.

피로도 계산 (Matlab 이용)

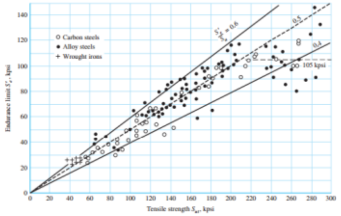
```
function y = cycle(Tmax,Tmin,mode)
Sut = 808; n = 200000/11; f = 0.82;
type = 'Ground'; d = 0.03;

torque = [0,10,20,40,100,200,300,360,400];
stress = [0,8.030, 1.606*10, 3.212*10, 8.031*10 ...
        1.606*10^2, 2.409*10^2, 2.892*10^2, 3.212*10^2];

siga = interp1(torque,stress,abs(Tmax-Tmin)/2)
sigm = interp1(torque,stress,abs(Tmax+Tmin)/2)

if Sut<1400
    Se2 = 0.5*Sut
else
    Se2 = 700;
end
```

선형성을 이용하여 σ'_a, σ'_m을 구한다.



S_{ut}가 1400보다 작으면 $S_e' = 0.5$ **x** S_{ut}이고 S_{ut}가 1400보다 크면 $S_e' = 700MPa$

```
switch type
    case 'Ground';
        a = 1.58; b = -0.085;
    case 'Machined';
        a = 4.51; b = -0.265;
    case 'Hot rolled';
        a = 57.7; b = -0.718;
    case 'As forged';
        a = 272; b = -0.995;
end

Ka = a*Sut^b        % 표면 계수
```

표면을 'Ground'로 처리하여 표면 계수를 고려한다.

```
if (1000*d>2.79) && (1000*d<51)
    Kb = 1.24*(1000*d)^(-0.107)
elseif (1000*d>51) && (1000*d<254)
        Kb = 1.51*(1000*d)^(-0.157);    % 크기 계수
end

Se = Ka*Kb*Se2


    Sf = siga/(1 - sigm/Sut)

    a = (f*Sut)^2/Se
    b = -1/3*log(f*Sut/Se)

    life = (Sf/a)^(1/b)


if (mode == 1) || (mode == 2) || (mode == 3)
    n = 4*n;
end

if life < 10^6
    y = n/life;
elseif life > 10^6
    y = 0;
end
```

Hole 부분의 shaft의 두께로 크기 계수를 고려한다.

표면과 크기를 고려한 내구한도을 구한다.

피로 수명 공식을 이용한다.

①,②,③번 mode(시가지)는 4번씩 반복되었다.

High cycle인 경우
D = n/N

Infinite life인 경우
D = 0

Damage factor 구하기

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
1	mode	1																					
2	Tmax	65	3																				
3	Tmin	0	-14																				
4	mode	2																					
5	Tmax	45	150	55	120	70	-130	10															
6	Tmin	0	0	0	105	-40	100	-75															
7	mode	3																					
8	Tmax	50	70	35	150	40	65	245	50	110	45	10	0										
9	Tmin	-70	0	0	-20	-40	10	10	-10	-195	-75	-35	-120										
10	mode	4																					
11	Tmax	45	150	20	60	245	60	360	30	70	50	20	20	75	20	80	65	100	50	65	50	70	0
12	Tmin	0	0	-120	0	-75	-30	25	-290	-20	25	-50	-290	-70	-290	-70	-290	-25	-25	10	30	50	-80

이전에 작성한 변동 하중

Untitled8.m

```
Tmax = [65 3 45 150 55 120 70 -130 10 50 70 35 150 40 ...
    65 245 50 110 45 10 0 45 150 20 60 245 60 360 30 70 ...
    50 20 20 75 20 80 65 100 50 65 50 70 0];
Tmin = [0 -14 0 0 0 105 -40 100 -75 -70 0 0 -20 -40 10 10 ...
    -10 -195 -75 -35 -120 0 0 -120 0 -75 -30 25 -290 -20 25 ...
    -50 -290 -70 -290 -70 -290 -25 -25 10 30 50 -80];
mode = [1 1 2 2 2 2 2 2 2 3 3 3 3 3 3 3 3 3 3 3 3 ...
    4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4];
minor = 0;
for i = 1:length(Tmax)
    minor = minor + cycle(Tmax(i),Tmin(i),mode(i));
    minor
end

```

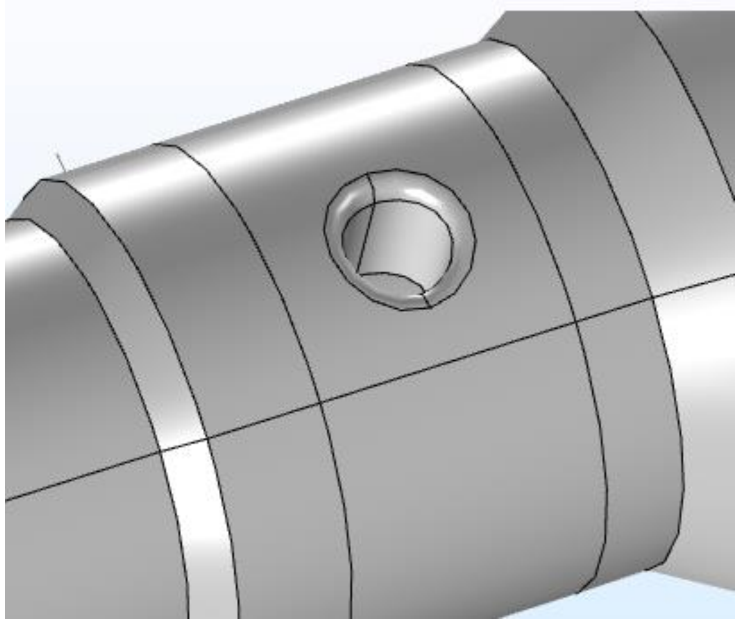
compute →

```
minor =

0.9556
```

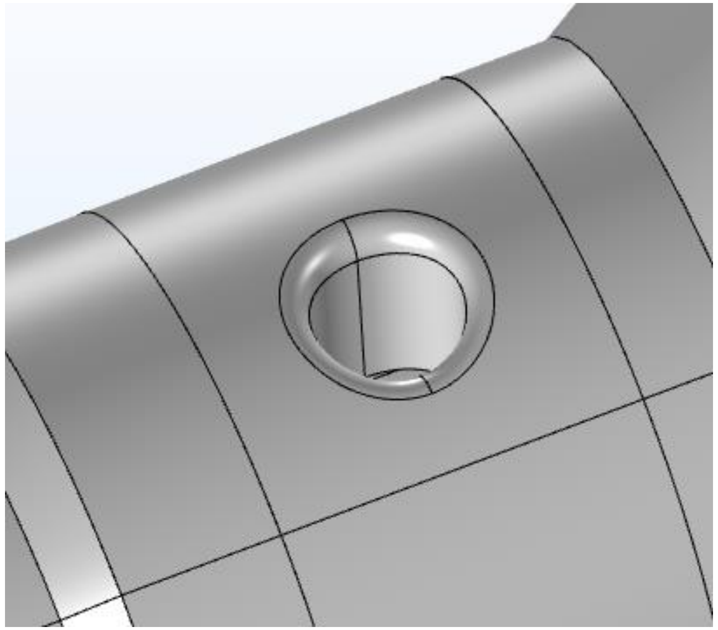
파괴이 일어나지는 않지만
D = 1에 거의 가까워 위험한 상황

오일구멍의 fillet을 달리 주었을 때 값 비교 (토크=360Nm)



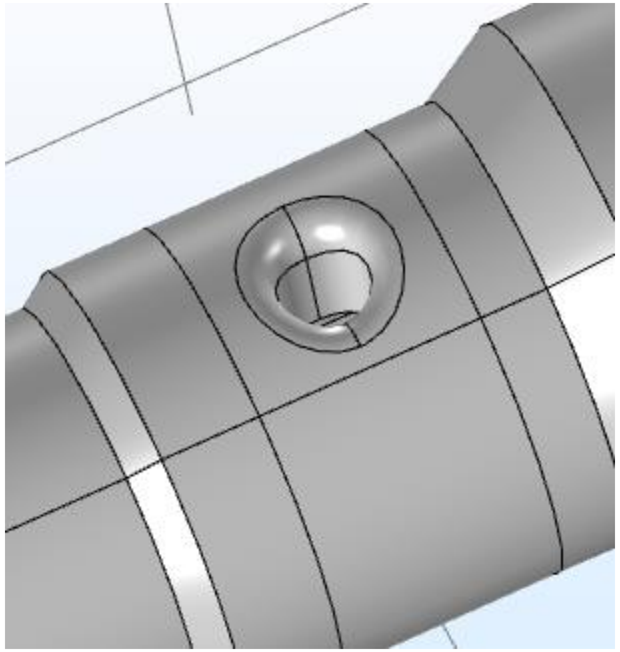
Fillet 0.7mm

von Mises stress (N/m^2)
2.8915E8



Fillet 1.0mm

von Mises stress (N/m^2)
2.8521E8



Fillet 1.4mm

von Mises stress (N/m^2)
2.7597E8

오일구멍의 fillet을 달리 주었을 때 Damage factor

Fillet 0.7mm	Fillet 1.0mm	Fillet 1.4mm
minor = 0.9556	minor = 0.8712	minor = 0.6953

파단 → 안전

D = 1에 거의 가까움

D가 0.7보다 작아짐

작은 fillet 두께 변화에도 안전한 정도는
민감하게 변화하는 것을 알 수 있다.

Q & A

Thank you