Product Sealing Concept and Hyper Elastic Simulation Study for Gasket Compression

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ABSTRACT *: The usage and application of Rubber Gaskets and O-Rings has become highly used technical solution for most of the electro mechanical products like Control Modules used in the automotive applications. To be meet the challenging Ingress Protection requirements from customer this becomes very important to verify the sealing material behavior with respect to the loading conditions for the product internal interfaces. One of the most important point is the compression of the rubber gasket which will thereby provide the required Ingress Protection to the product in the given ambient environment. Role of Finite Element Modeling of the Rubber material is also playing a crucial role in verification of sealing concept at pre-manufacturing stage only. By this simulation design engineer can easily judge and verify the internal product sealing interfaces before releasing the same for tooling development and production.*

KEYWORDS – *Gasket, Hyper Elastic Materials, Electronic Power Steering, Mooney Rivlin Model & Steel Safe Considerations.*

I. INTRODUCTION

A gasket is a mechanical seal which fills the space between two or more mating surfaces, generally to prevent leakage from or into the joined objects while under compression. The material of gasket is usually a Rubber variant with different shore hardness depending on the application and sealing requirements.

When some specific load is applied and then removed on general materials they show elastic behavior returning to its original state within the range where the relationship between load and deformation is linear. However, in case of rubber-like materials they show hyper-elastic characteristics representing elastic behavior in the range of large deformation showing nonlinear relationship between load and deformation.

So, we can say that Hyper Elastic materials are the special class of materials which tends to respond elastically when they are subjected to very large strains. They show both a nonlinear material behavior as well as large shape changes. This is clear now that most of the sealing components (customized gaskets, O-Rings etc.) exhibit hyper-elastic properties when subjected to different loading conditions.

Thus, many attempts have been made to obtain theoretically the stress-strain curves from experiments on the deformation of highly elastic rubber-like materials. However, since the deformations, which rubber-like materials undergo, are too large and the aspect of behavior shows a significant difference depending on the materials, it is difficult to decide a stress energy density function which adequately represents the stress-strain relation from experiments. So, this also becomes difficult for creating Finite Element Mathematical Model of Rubber like material as material inputs could not be as per practical database. However, there are some specific tests which are performed experimentally to verify the hyper elastic properties of any rubber material to be used as an input for Finite element Modelling of the sealing component.

In this paper we will investigate the compression analysis based on the product sealing interfaces which helped the designer to understand the sealing reliability and to verify the Ingress Protection before the design release to component suppliers. The product here considered is Steering Control Module used in passenger vehicles to control the steering inputs from driver by managing the motor output.

2. PRODUCT DETAILS

Electronic Power Steering (EPS) generates the power-assist by means of an electric motor whose force is fed into the rack or steering column by a servo gear unit. The electric motor is powered by the on-board wiring. The motor is actuated by power electronics integrated into the electric ECU of the EPS.[1]

Steering Control Module (SCM) Power units are found on electronically controlled power steering systems as opposed to the older hydraulically controlled systems. The control unit applies torque through the motor, which connects to the steering column or the steering gear. This allows assistance to be applied to the vehicle, depending on certain driving conditions and demand. EPS/SCM uses torque sensors to identify the driver's purpose.[2]

The module calculates the required steering support based on the incoming signals from the sensor system. The module also controls the EPS system's electric motor power supply.

Fig.1: Electronic Power Steering

Fig.2: Electronic Power Steering Control Module

3. PRODUCT DESIGN

Fig.3: 3D CAD Model of SCM

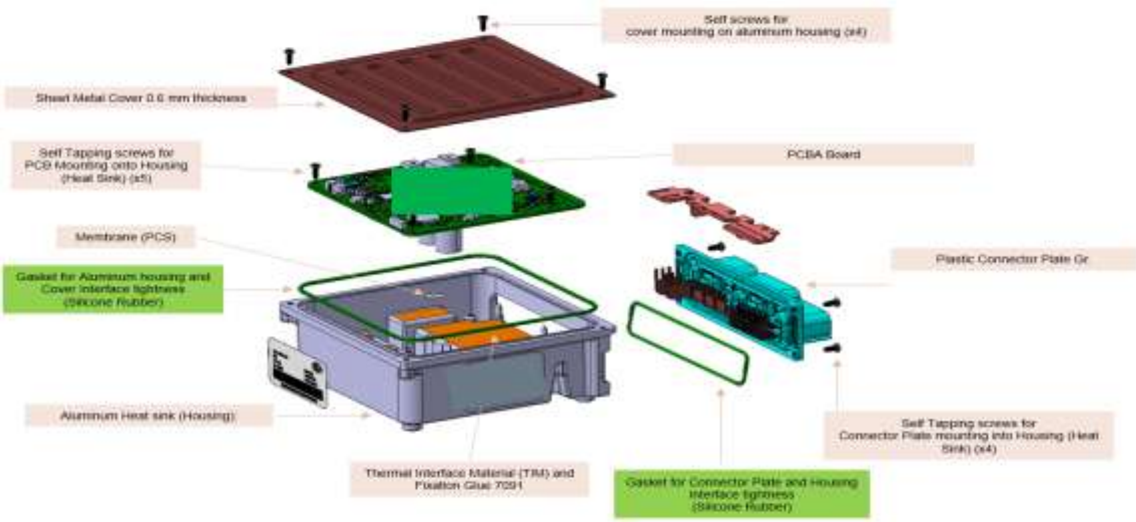


Fig.4: Exploded View of SCM

The Steering Control Module (SCM) in Fig.3 is exploded in Fig.4 to visualize the internal mechanical components including the sealing interfaces. Here we can see clearly that there are two prime sealing interfaces in the product (Green highlighted in Exploded View in Fig.4): -

1. Interface 1: Top Sealing interface between Sheet Metal Cover and Aluminum Heat Sink (Housing)
2. Interface 2: Side Sealing interface between plastic Connector Plate and Aluminum Heat Sink (Housing)

Refer below figure for more details: -

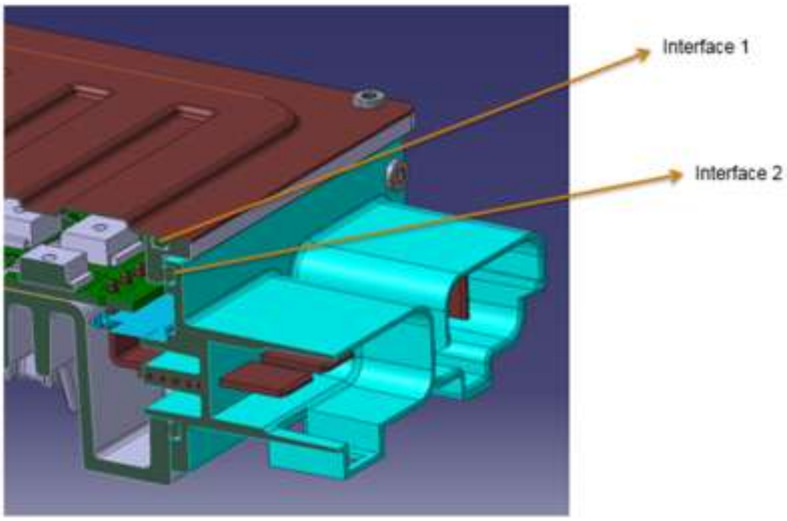


Fig.5: Sealing interfaces of SCM

Both the gaskets are compressed and secured in the groove by the standard screw torqueing at the sealing interfaces for M3 self-tapping screws.

The intent of this research paper is to verify the gasket compression at both the sealing interfaces through Finite Element Analysis (Hyper-Elastic Simulation) after the screw torqueing. This simulation would be very beneficial to analyze whether the number of screws and the torque is enough for the gasket compression to ensure the Ingress Protection at both the sealing interfaces.

4. MATERIAL PROPERTY

Component	Material
Cover	CRCS D grade7
Connector Plate Terminals	CuSno 15 R4208
Gasket	EPDM 45ShA9
Plastic Connector Plate	PBT GF-3010
Housing	Aluminum ADC-1211
Retainer plate	Ultramid B3ZG3 (PA6 GF-15)

Material Properties of the Gasket Material: -

As we know that Rubber is hyper elastic material, so we need to define the elastic constants for the same. These constants will be used as inputs for the Finite Element Analysis.

We considered Mooney Rivlin Model for the definition of Elastic Constants.

Mooney-Rivlin model

Mooney derived an expression for the strain energy function for rubber starting from several assumptions. A Mooney-Rivlin model, which was introduced by Melvin Mooney and Ronald Rivlin is a hyper-elastic material model.

(1) The material is homogeneous and free from hysteresis;
(2) The material is isotropic initially and throughout the deformation;
(3) The deformations occur without a change in volume (i.e. incompressible);
(4) The traction in simple shear in any isotropic plane is proportional to the shear.

Refer below the Hyper elastic model input for current simulation: -

Material	C01	C10	D1
EPDM 45ShA	0.058	0.232	0.580
EPDM 37ShA	0.041	0.165	0.412
EPDM 35ShA	0.041	0.162	0.406

5. LOAD CASES

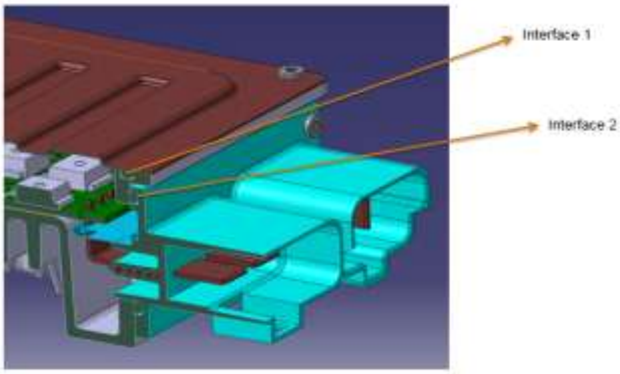
1. Static strength of EPS for gasket (Sh 45A) for compression force and displacement.
2. Static strength of EPS for gasket (Sh 37A) for compression force and displacement.
3. Static strength of EPS for gasket (Sh 35A) for compression force and displacement. (Cover Thickness increased to 0.8 mm)

6. ASSUMPTIONS AND BOUNDARY CONDITIONS

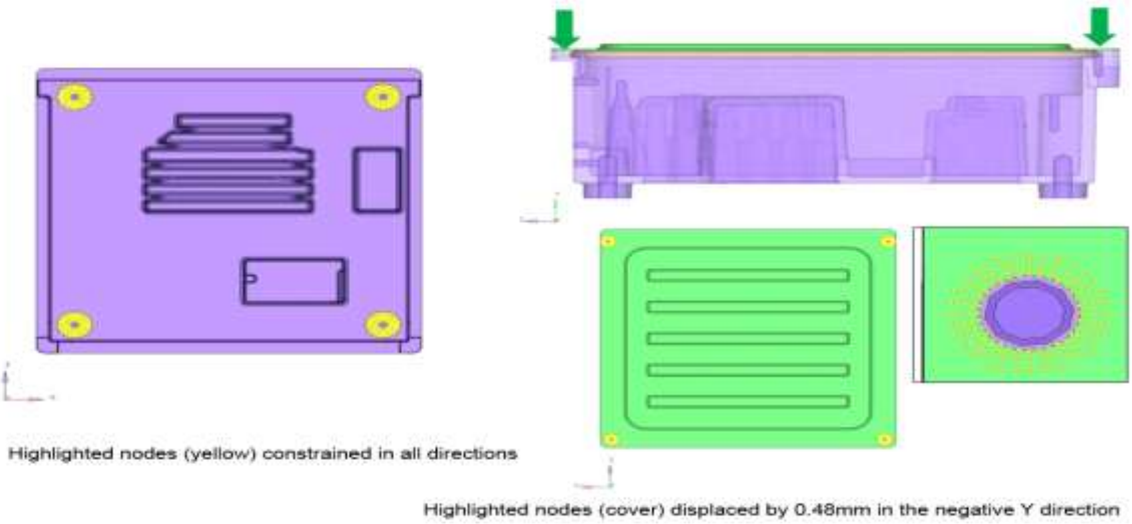
Assumptions

- Material properties for the cover (CRCS) considered as linear.
- Weld lines and fiber orientation not considered for the simulation.

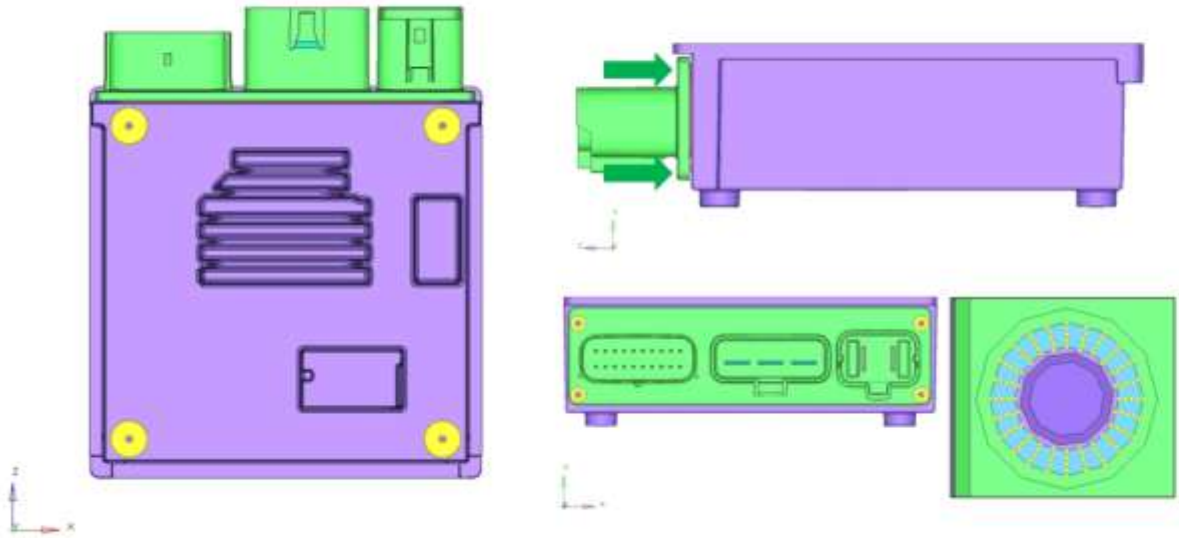
Boundary Conditions



Interface_1_Top Cover and Housing Interface



Interface_2_Connector Plate and Housing Interface



Highlighted nodes (yellow) constrained in all directions

Highlighted nodes (bush) displaced by 0.5mm in the negative Z direction

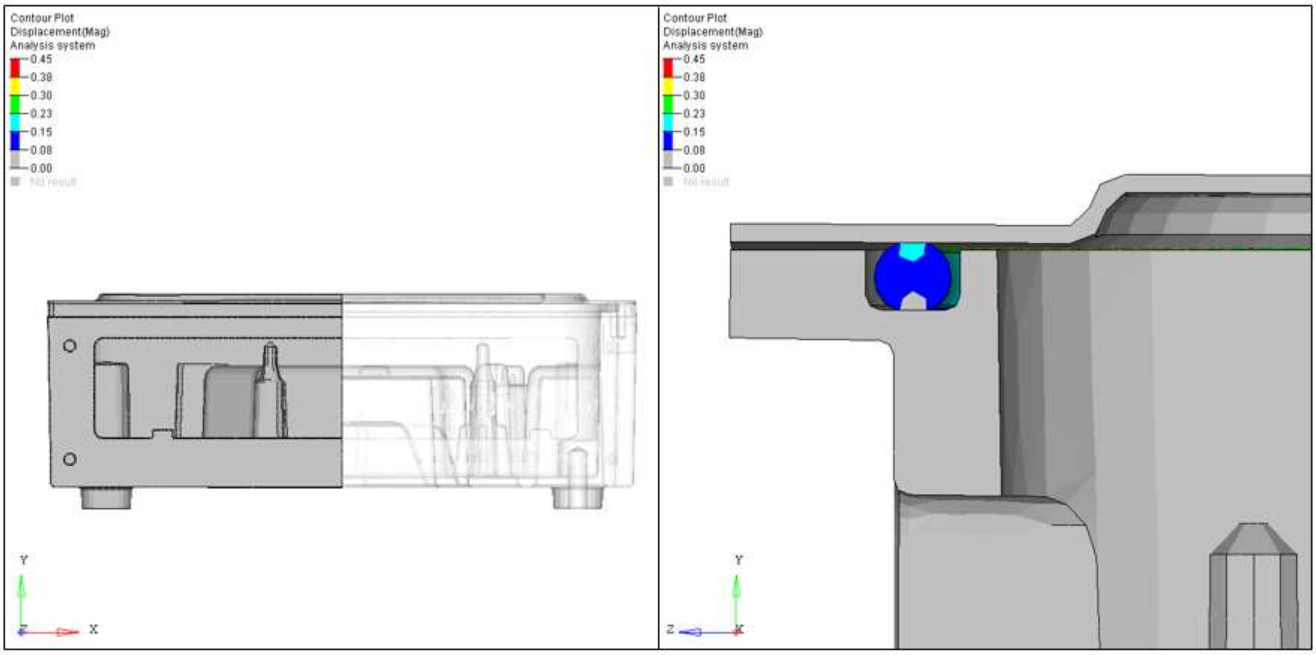
6. RESULTS AND SUMMARY

Load Case 1: Static strength of EPS for gasket (Sh 45A) for compression force and displacement

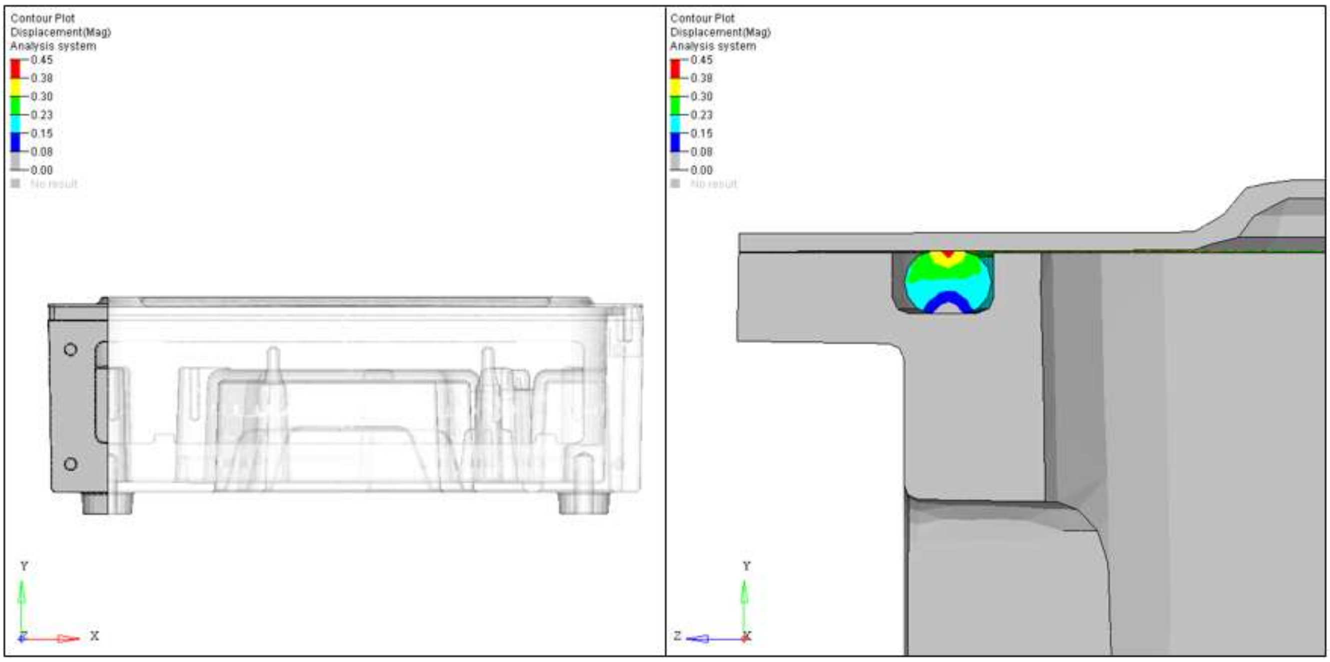
Interface 1:

For cover interface (Interface 1) we see 0.45 mm displacement due to compression near the screwing areas and 0.15 to 0.23 mm in the middle section. (critical)

The contact force between the gasket and the cover is 127N.



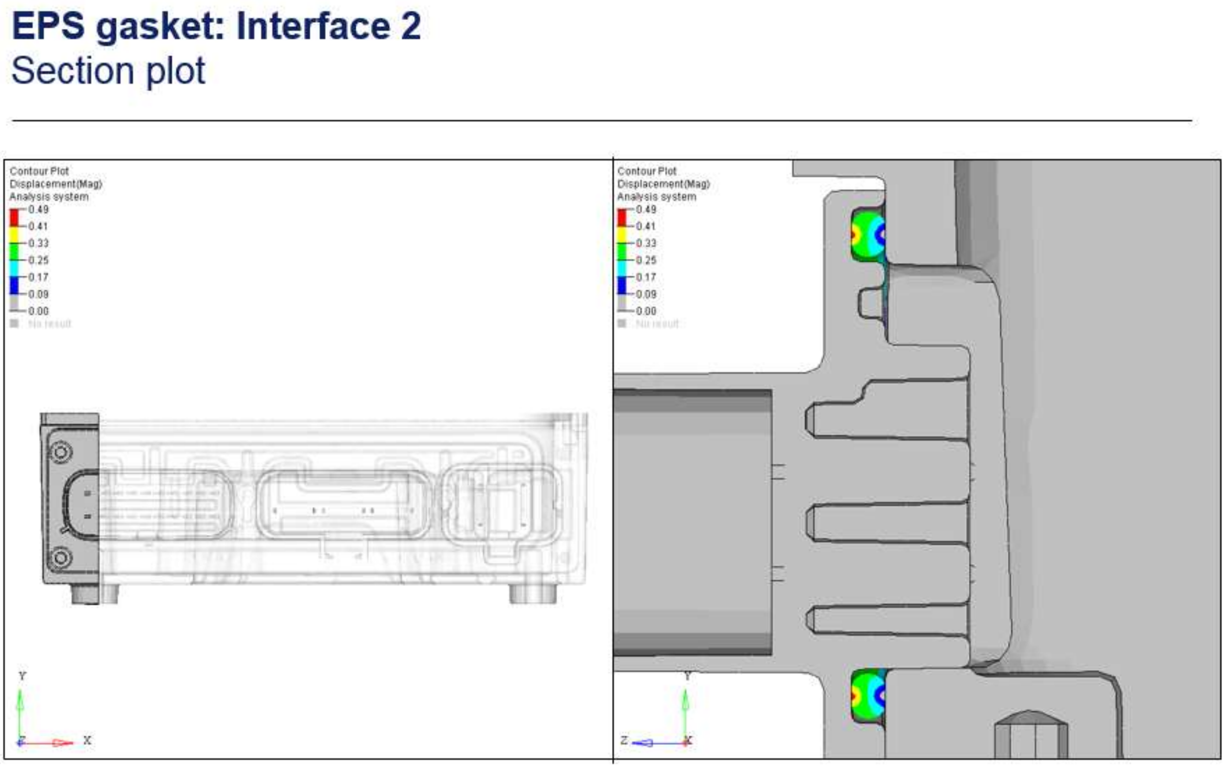
Gasket displacement due to compression



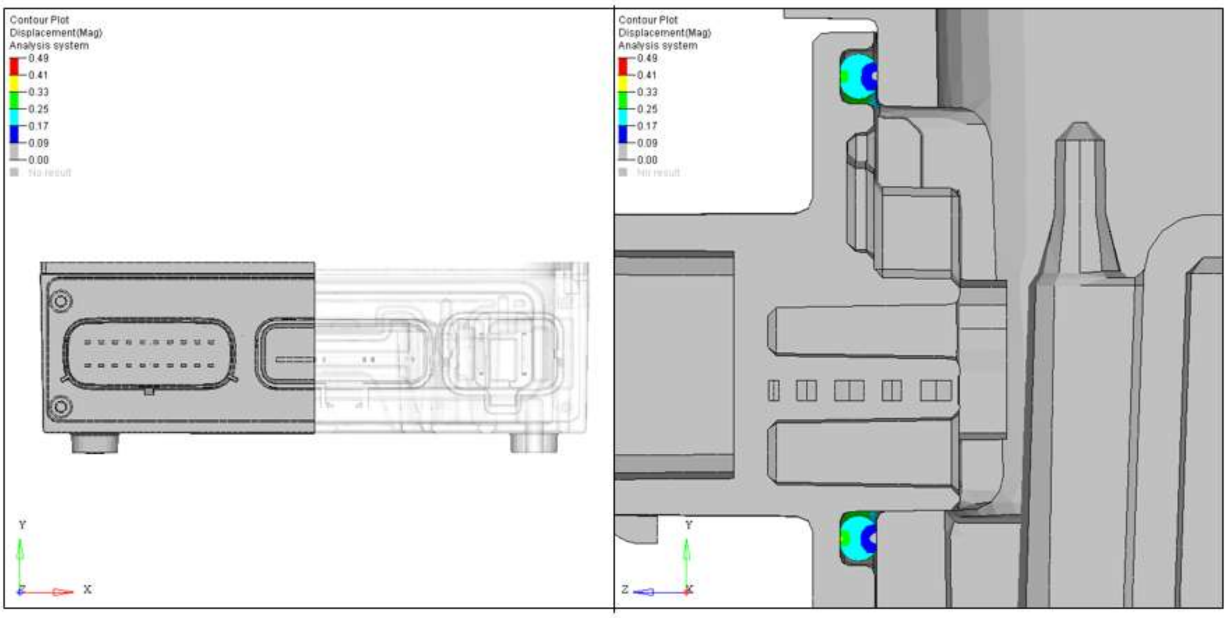
Gasket displacement due to compression

Interface 2:

For connector plate interface (Interface 2) we see 0.49 mm displacement due to compression near the screwing areas and 0.25 to 0.33 mm in the middle sections. Displacement of 0.5 mm is identified in assembly direction (-z dir.)
The contact force between the gasket and the connector is 98N.



Gasket displacement due to compression



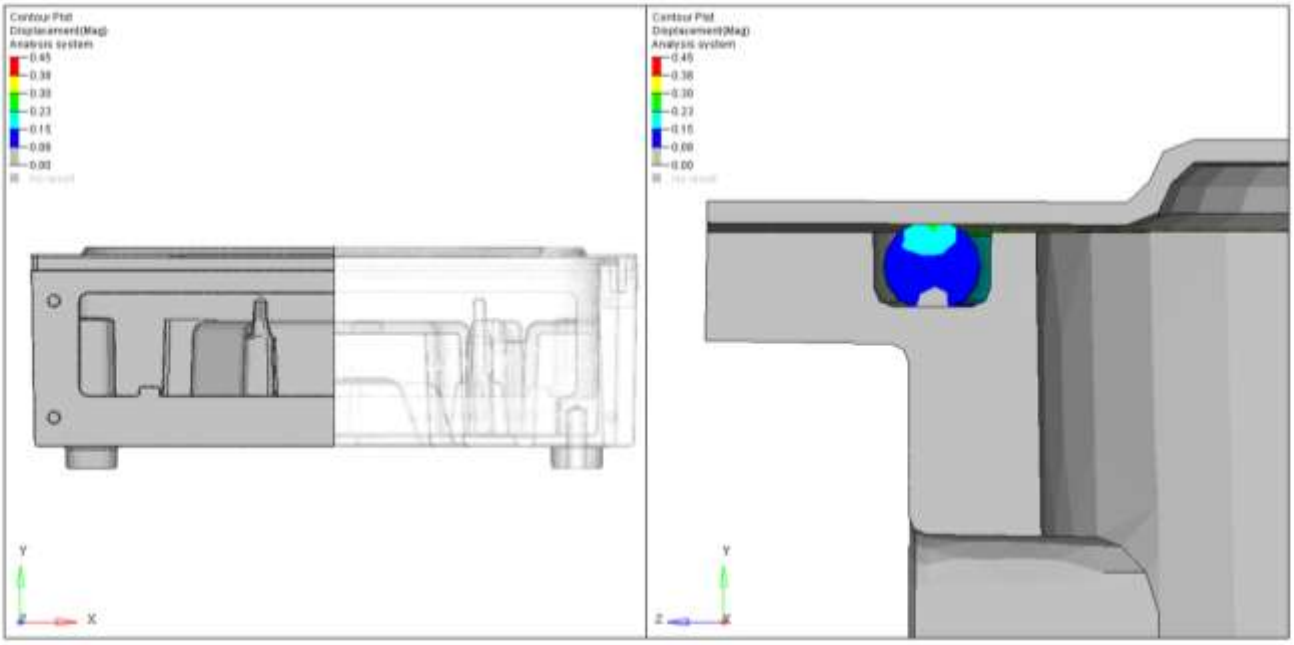
Gasket displacement due to compression

Load Case 2: Static strength of EPS for gasket (Sh 37A) for compression force and displacement

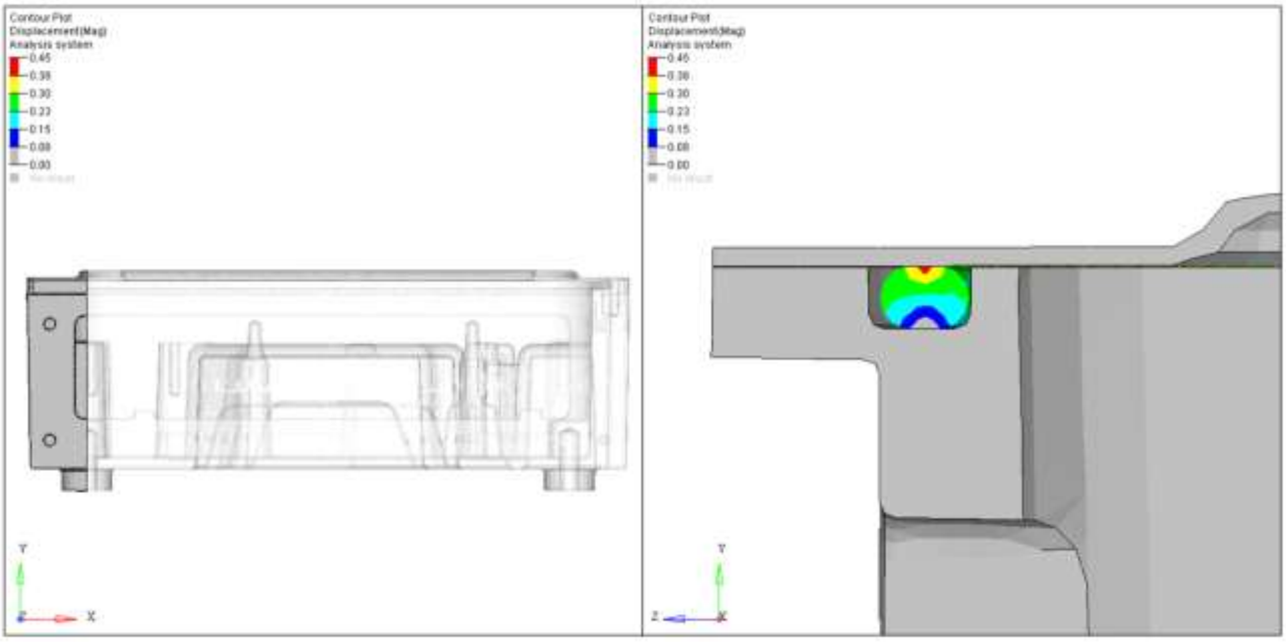
Interface 1:

For cover interface (Interface 1) we see 0.45 mm displacement due to compression near the screwing areas and 0.23 to 0.30 mm in the middle section. (critical)+

The contact force between the gasket and the cover is 107 N.



Gasket displacement due to compression

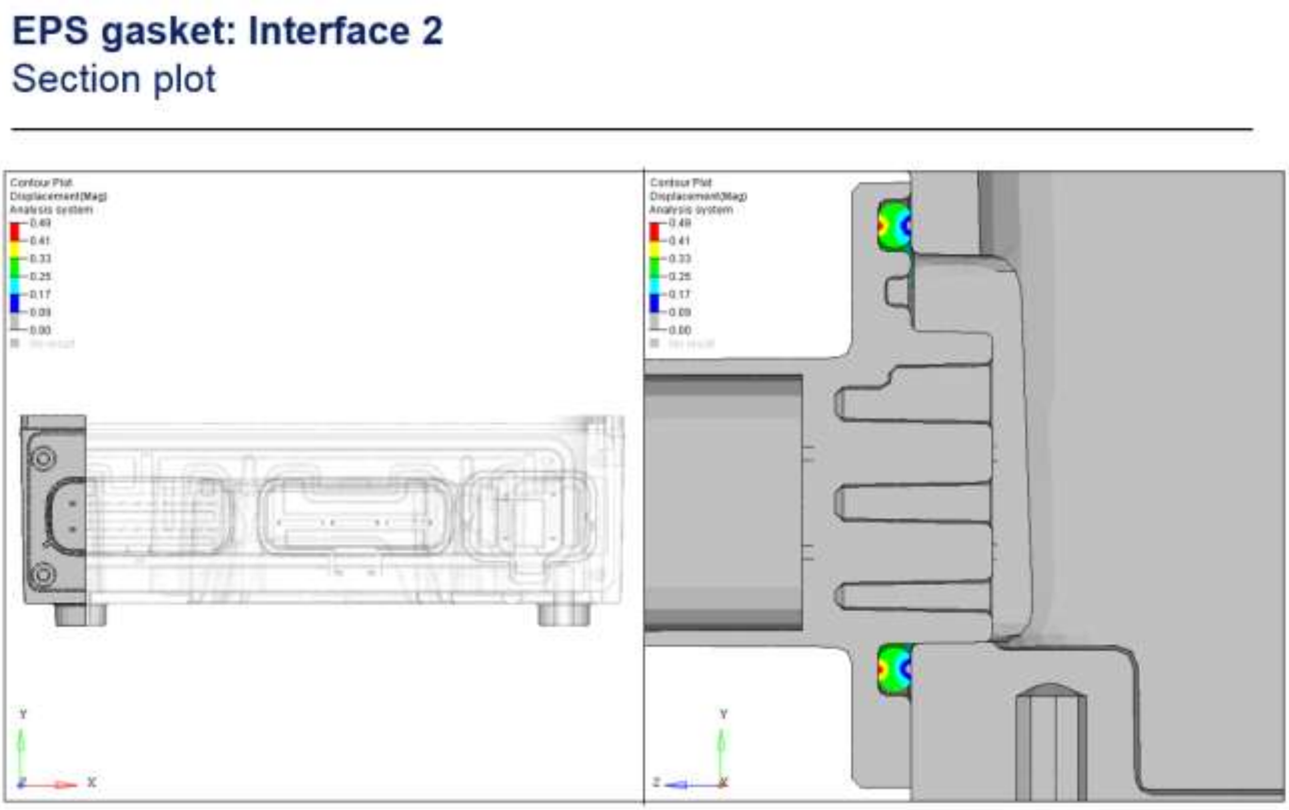


Gasket displacement due to compression

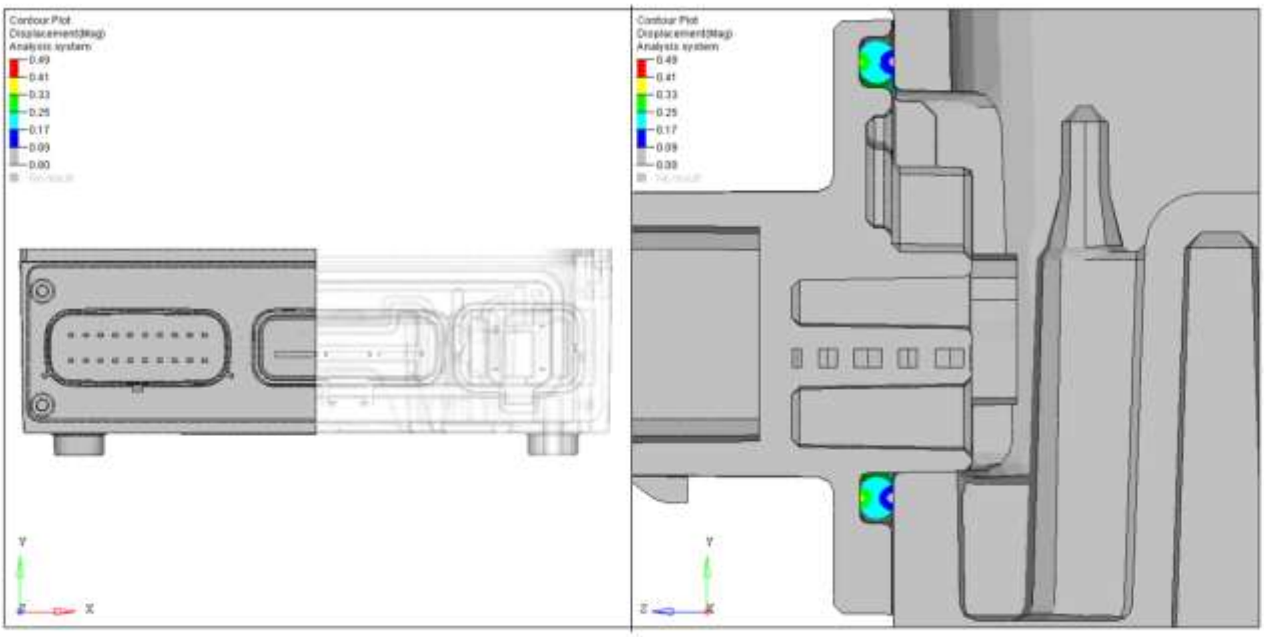
Interface 2:

For connector plate interface (Interface 2) we see 0.49 mm displacement due to compression near the screwing areas and 0.33 to 0.41 mm in the middle sections.

The contact force between the gasket and the connector is 80 N.



Gasket displacement due to compression


Gasket displacement due to compression

Summary for Load Case 1 and 2

Iteration 1: Gasket Material with 45 Shore A Hardness

Conclusion: As per our study we would go ahead in two steps > Taking silicone-based rubber hyper elastic constants with lower shore hardness (35-40A) and at next level we will investigate the possibilities to have extra screws / clamping (DV Stage)

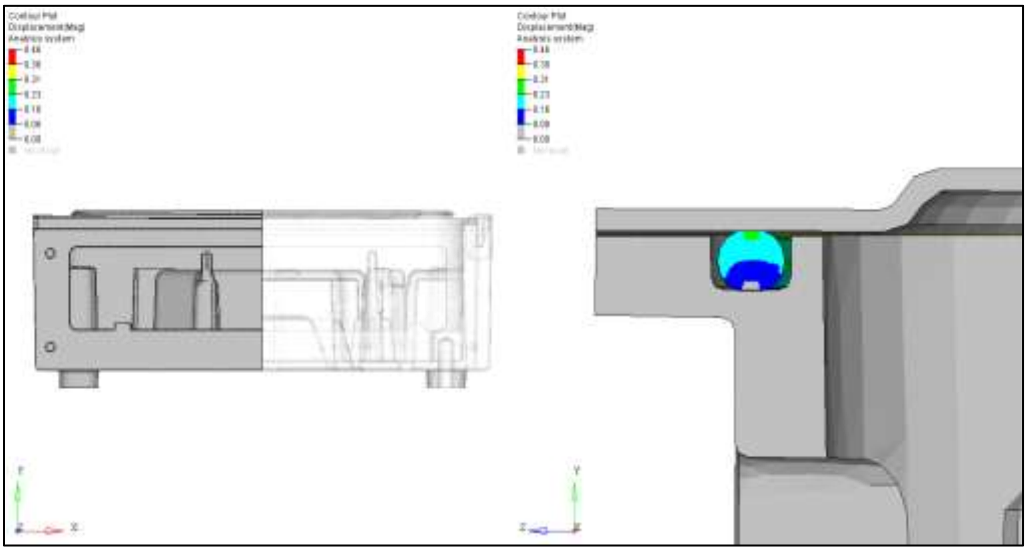
Iteration 2: Gasket Material with 37 Shore A Hardness

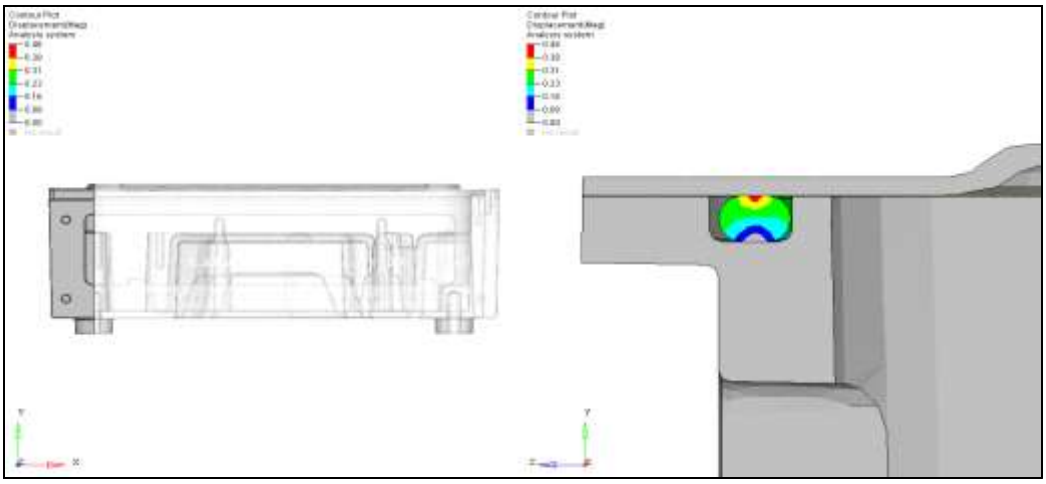
Conclusion: Bit improved observations we see on Connector Plate Interface but for the cover interface there is a bit improvement but still that is in critical zone.
There are two modification which needs to be compiled together for the desired results.
One is to go with Cover with thickness 0.8 mm and other is using the Gasket Material with Shore Hardness 35A.

Note: Hyper Elastic constants for the Gasket Material C10, C01 and D1 provided for simulation are theoretically calculated which are just giving a referable observation.
For 100% practical simulation, we must provide practical tested values of the rubber material which will require extra cost and budget.

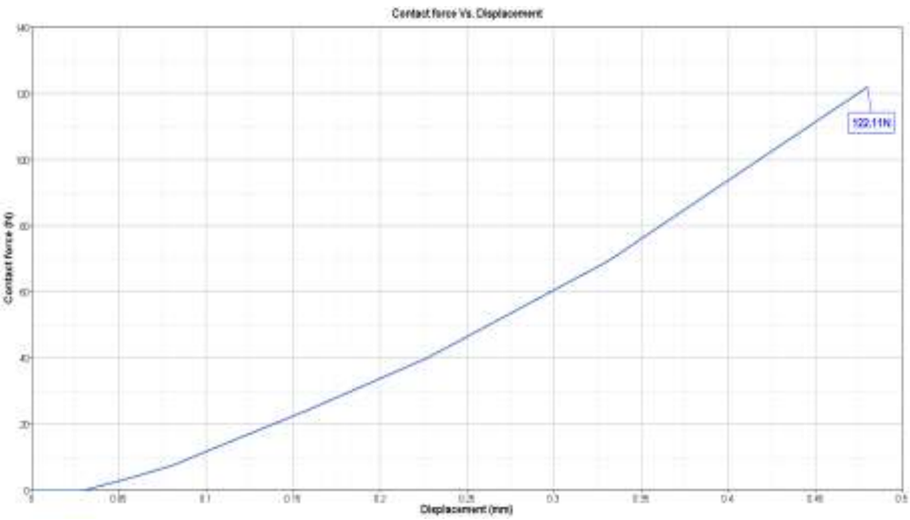
Load Case 3: Static strength of EPS for gasket (Sh 35A) for compression force and displacement (Cover Thickness 0.8 mm)

Interface 1:
- Maximum displacement observed in the cover is 0.48mm.
- Maximum displacement observed in the gasket is 0.458mm (Cover 0.6mm, Sh37A: 0.453mm).
- Maximum von Mises stress observed in gasket material is 0.32MPa (Compressive).
- The contact force between the gasket and the cover is 123N.



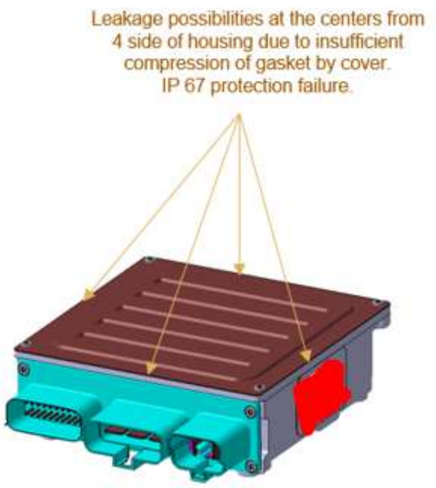


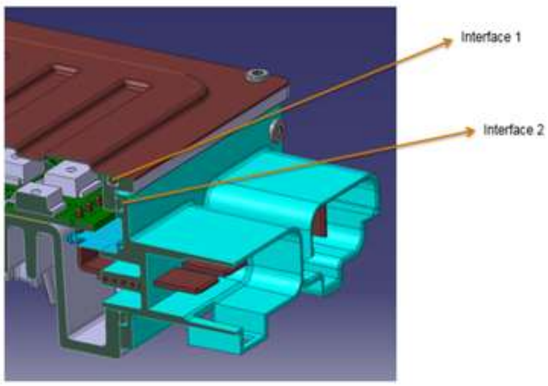
Contact force (normal) of 123N between the gasket and the cover



7. COUNTERMEASURES AND PROPOSED DESIGN OPTIMIZATIONS

Risk Identified from all the Load Cased simulated: -





Observation in Hyper Elastic Simulation for Gasket Compression

- Gasket Material with 45 Shore A Hardness

Interface_1	Interface_2
For cover interface (Interface 1) we see 0.45 mm displacement due to compression near the screwing areas and 0.15 to 0.23 mm in the middle section. (critical) The contact force between the gasket and the cover is 127N.	For connector plate interface (Interface 2) we see 0.49 mm displacement due to compression near the screwing areas and 0.25 to 0.33 mm in the middle sections. Displacement of 0.5 mm is identified in assembly direction (-z dir.) The contact force between the gasket and the connector is 98N.

- Gasket Material with 37 Shore A Hardness

Interface_1	Interface_2
For cover interface (Interface 1) we see 0.45 mm displacement due to compression near the screwing areas and 0.23 to 0.30 mm in the middle section. (critical) The contact force between the gasket and the cover is 107 N.	For connector plate interface (Interface 2) we see 0.49 mm displacement due to compression near the screwing areas and 0.25 to 0.33 mm in the middle sections. Displacement of 0.5 mm is identified in assembly direction (-z dir.) The contact force between the gasket and the connector is 98N.

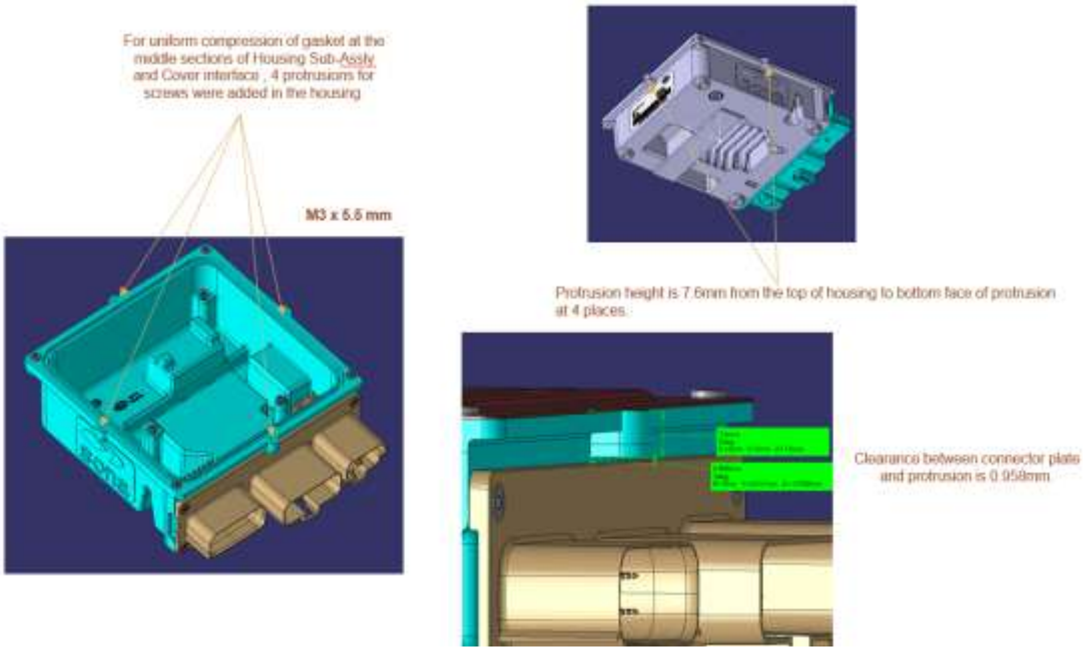
- Gasket Materail with 35 Shore A (0.8 mm cover thickness) Hardness

Interface_1
Maximum displacement observed in the cover is 0.48mm. Maximum displacement observed in the gasket is 0.458mm (Cover 0.6mm, Sh37A: 0.453mm).

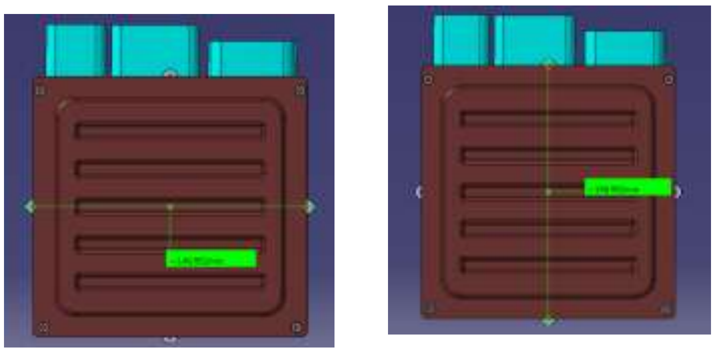
Countermeasure
Additional screws (x4) to be provided on Interface 1 For uniform compression at the middle section of the mating interface to avoid the possible leakage.

Countermeasure: Concept with Additional Screws for Uniform Gasket Compression

Protrusion and Screw Land Details:



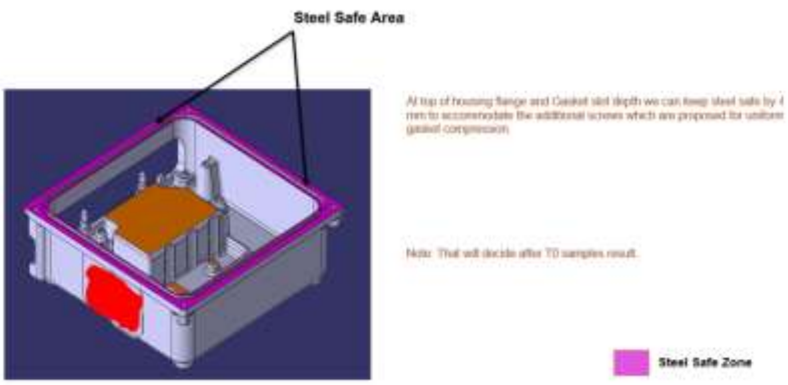
Change in Product Packaging Documentation:



Product packaging dimensions are increased in x, y and z directions.

- Product Height is increased to 50 mm from 46 mm (Z dir.)
- Product Length and width increased to 146.95 mm from 140 mm (X&Y dir.)

Steel Safe Considerations in Tooling:



8. CONCLUSIONS

We see that the Finite Element Analysis has helped a lot to understand the compression behavior of the rubber gasket at both the interfaces. This was an early input for designer to understand the gasket behavior and countermeasures to be taken prior to tooling manufacturing. Most important factor is the gasket compression based on which we verified the Ingress Protection interfaces, uniform compression on overall gasket surface area is important to confirm the IP. The attribute responsible for the compression was dependent on the screw torque distribution and material behavior of the interfacing mechanical components.

The inputs achieved could be then taken up for the design optimization and in parallel for customer approval if in case wee see increase in product packaging dimensions. These will be important steps to obtain the design release and initiate the tool kick off activities.

References

[1] Steering Handbook – Chapter 15: Peter Pfeffer, Automotive Engineering (FK03) , Munich University of Applied Science (Munich, Germany)

[2] https://www.yourmechanic.com/article/symptoms-of-a-bad-or-failing-power-steering-control-unitNote that the journal title, volume number and issue number are set in italics.

Fig 1: Steering Handbook – Chapter 15: Peter Pfeffer, Automotive Engineering (FK03) , Munich University of Applied Science (Munich, Germany)

Fig 2: https://alphaautomotive.com/oem-hyundai-sonata-power-steering-control-module-56340-c2500-591hy1q17-229591