Development of a Separator Plate for Valve Bodies in a Vehicle Automatic Transmission

Harald Rebien, Tobias Tauscher, Rohit Ramkumar

DANA® Holding Corp., Power Technologies Group

Abstract

Object:

Development of a Separator Plate for Valve Bodies in a Vehicle Automatic Transmission

Automatic transmissions in light vehicles are complex hydraulic systems. The hydraulic control unit (HCU) distributes oil to shift valves and sliders. The separator plate as a part of it needs to seal all fluid channels and provides fluidic connections between the flanges.

Problem:

Nowadays the automatic transmissions need to be an economically optimized system. To meet CO_2 goals, the transmission has to be more efficient. One possibility is to raise the operating pressure in the hydraulic fluid. But this leads to a higher leakage rate and thus larger pressure pumps are required. To overcome this dilemma several innovative solutions were needed to develop a new generation of separator plates. These replace the conventional separator plates in new high efficient automatic transmissions.

Lower leakage rates at higher pressure demand a more effective sealing solution. If this solution works particularly efficient it could provide an opportunity to reduce the amount of bolts required for the joint. This opens the possibility of more flexible design of the hydraulic channels.

Results:

With the help of Abaqus® it was possible to create a FEA model which described the real world good enough to predict the sealing performance, flange and valve seat distortions at different operating conditions. Confidence in the model brought us in the position to develop a new high performance gasket. The sealing performance is much higher and can be adapted to the customers' design needs like hydraulic pressure, flange stiffness and bolt positions. Comparisons

with traditional separator plates confirmed that it is possible to reduce the number of bolts in the joint. This leads to a better hydraulic channel design at lower cost.

Conclusion:

Using CAE technology helped us to create a simulation driven design. New innovative sealing technology could be developed and applied to individual customer demands.

Value:

With the new innovative separator plates DANA® could convince customers to apply the new technology in their products. Additionally this new innovative separator plate is nominated for the PACE-Award.

Keywords:

automatic transmission, powertrain, drivetrain, automotive, bending, bolt load, CAE, deformation, design optimization, FEA, forming, gasket, sealing pressure, transportation,

Body of Paper

a) Introduction

As a global technology leader in efficient power conveyance and management solution DANA® develops products that enable their customers to achieve their sustainable objectives. In this case DANA® was focused on improving the efficiency of automatic transmissions in light vehicles.

As many governments tighten environmental regulations, the automotive industry has to find fields to reduce their CO_2 output.

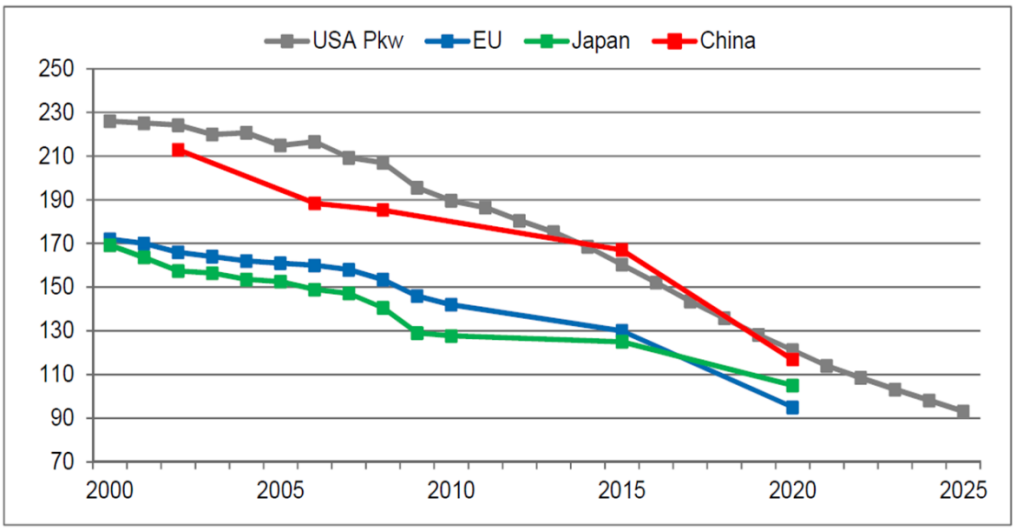


Figure 1. Global legislations permanently push down the CO_2 limits. CO_2 limit [g/km]

The powertrain, including engine and output side, offers many options to bring down the amount of CO_2. On the one hand is the reduction of the fuel needed, on the other hand the better usage of the power provided by the engine. This puts the focus on the gear box. While mechanical gears have in general a high efficiency, automatic transmissions have more potential. The HCU needs energy to actuate valves and sliders.

b) Functioning of Separator Plates

Automatic transmissions in light vehicles are complex hydraulic systems. To change gears, oil in hydraulic channels needs to activate the right valves. These hydraulic channels are arranged mainly in two valve body flanges. The separator plate separates the channels within each flange and from one body flange to the other. Additionally the separator plate needs to provide at some locations a fluidic connection between two channels. Beside this, the separator plate has to manage

low bolt forces, avoid distortion in the valve body flanges and has to be durable under all conditions.

c) Benchmark

At the beginning of this innovation a benchmark showed different solutions and their pros and cons. The conventional separator plates had

- Low sealing potential due to low sealing features and recovery
- High bolt load loss due to plastic deformations
- Cross-channel leakage due to low sealing potential
- Layout for low pressure due to used design and materials
- Erosion and delaminating potential due to used materials
- Contamination Risk (cleanliness) due to used materials and process

Examples:

Figure 2. Steel plate -> low sealing potential

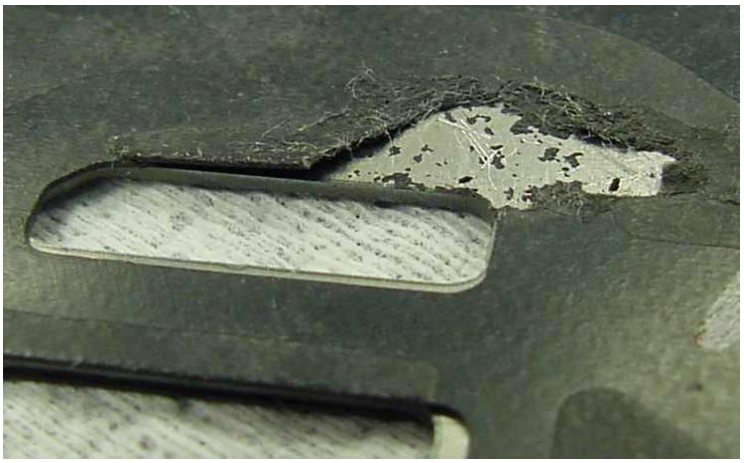


Figure 3. Soft gasket plate -> low robustness

d) Development targets

The efficiency of transmissions depends on their torque. High efficiency transmissions need to have the advantage at their most frequent driving conditions. This is at low torque.

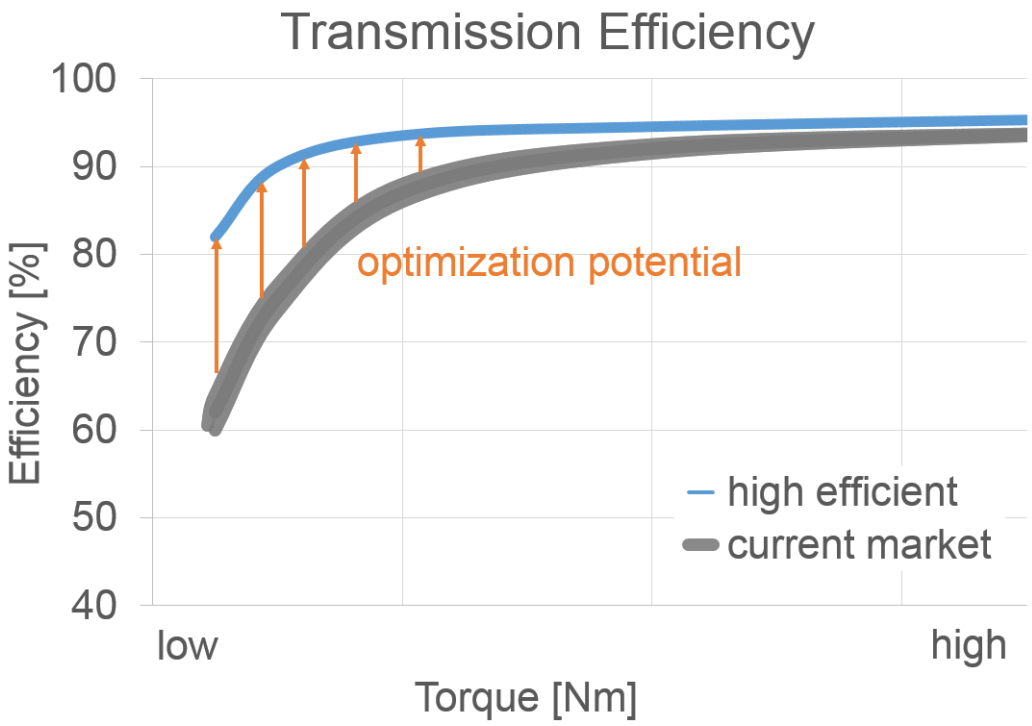


Figure 4. Transmission efficiency

DANA®'s MLS transmission separator plates enable OEMs to have the following design features.

- smaller oil pump, through lower leakage rate
- higher pressure, through higher sealing performance
- Lightweight design, through used layout and material
- pressure storage, through very low leakage rate

This is enabled through

- Improved transmission efficiency
    - Supports smaller oil pumps
    - Enables pressure storage
    - Reduces package size
- Lightweight design
    - Fewer bolts
    - Reduced component size and weight
- Enhanced cleanliness
    - Increased reliability
    - Decreased warranty cost

e) Coating improvement

A drastic improvement in the coating development enables a softer sealing design. A soft and more flexible coating is able to adapt to the surface roughness. Less pressure is required to press the coating into the uneven surface.

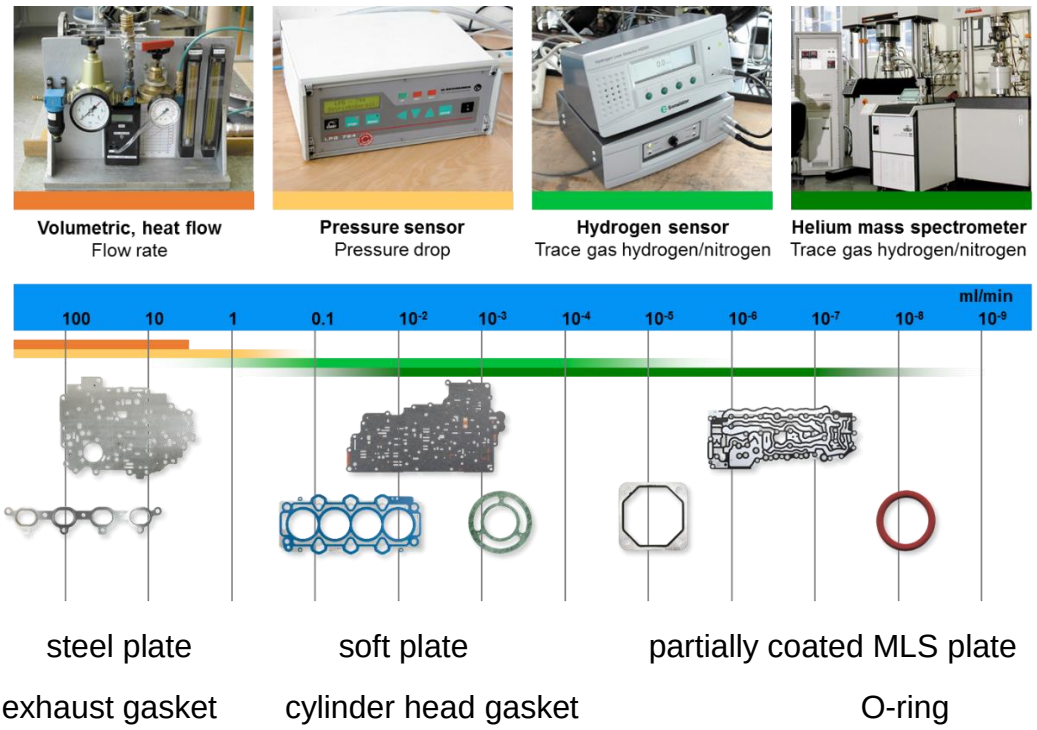


Figure 5. Partially coated multi-layer steel transmission separator plates show best sealing potential

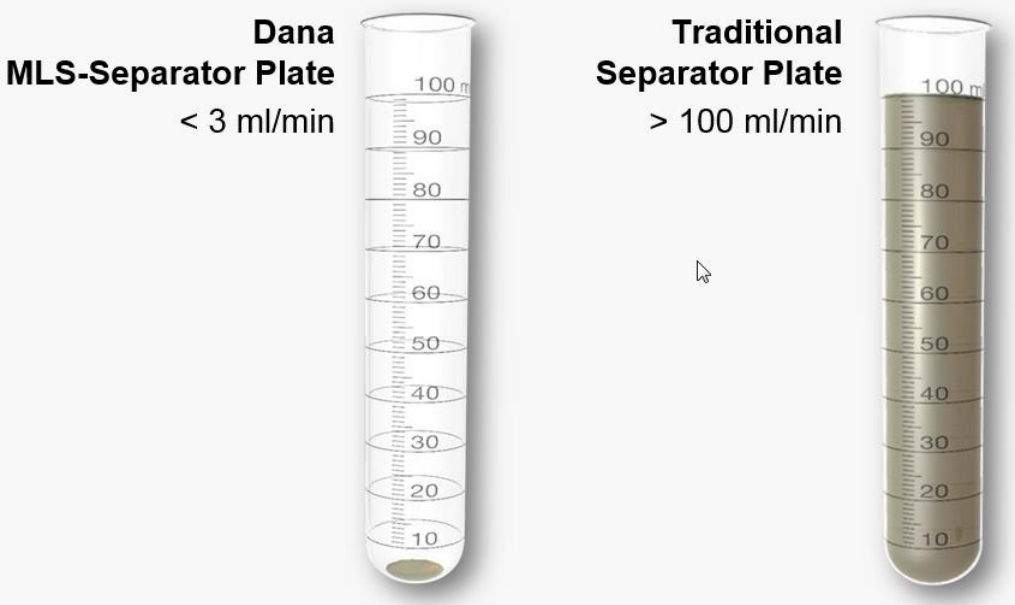


Figure 6. Comparison of leakage rate

With the reduced pressure it is possible to use less bolts and apply less bending at the flanges. Low bending is required to guarantee a reliable function of the valves and sliders in the flanges. The goal is now to find a design which on one hand is able to seal all channels and on the other head bends the flanges as little as possible. Only the custom-tailored sealing beads at the right place will lead to an optimal gasket layout.

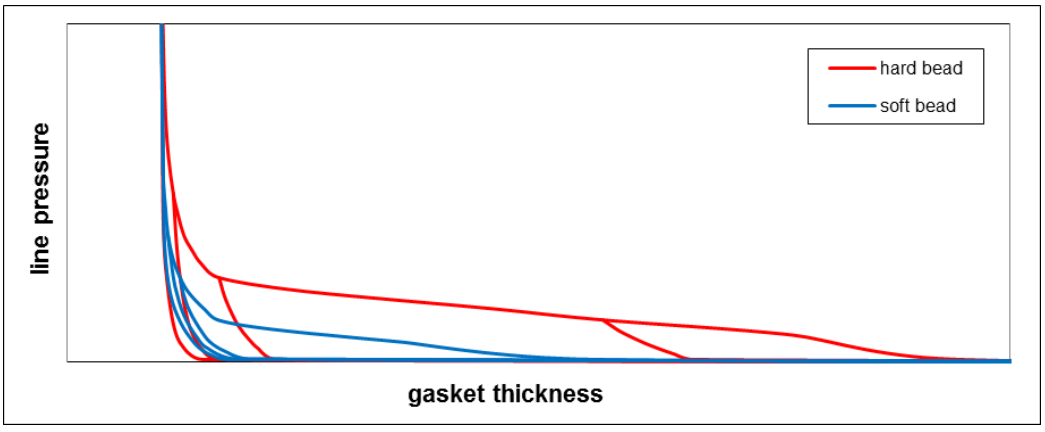


Figure 7. Load deflection curves of two different beads

f) Simulation

Abaqus®, as a strong CAE tool, helps us to achieve this goal. With Abaqus® we can do a lot of upfront simulations to examine the parts that should be sealed. In doing so, we observe the responses of the valve and actuator body and the separator plate of the HCU to different loads and boundaries. These loads and boundaries can be bolt forces, plate thickness, material and operating conditions like fluid pressures and temperatures. The responses are bending of the flanges, cylindricity of the valve bores, sealing gaps and sealing pressures.

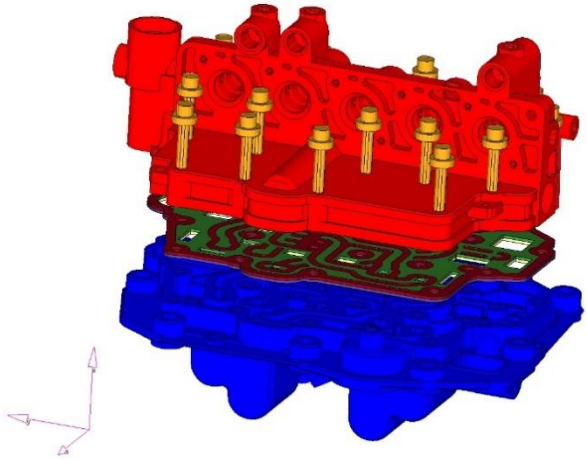


Figure 8. FEA-Model of a HCU of an automatic transmission

The separator plate is modeled with solid elements. In the sealing area they represent the loading- and unloading characteristics of the beads. These loading- and unloading curves are measured at our physical laboratory.

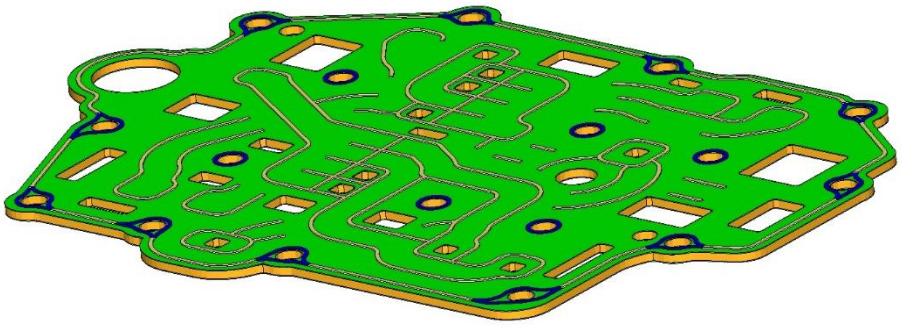


Figure 9. FEA-Model of the separator plate

When assembling the HCU it is important to know the bolt forces at the end of the bolt tightening sequence. This way, we can use Abaqus® to simulate the assembling and examine the bolt load loss during the tightening sequence. Besides the flanges and the tightening sequence, the gasket also has an influence on the bolt forces after assembly. In the case presented in the following chart, the bolts were tightened two times. The chart below shows the bolt load history and also indicates that at the end of the tightening process, all bolts are tightened properly.

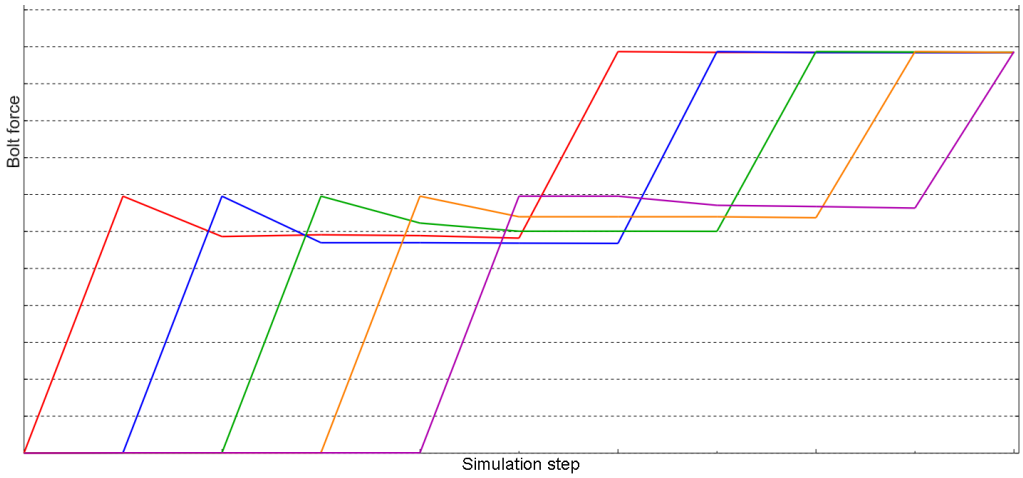


Figure 10. Example bolt load history

The following table shows the dynamic sealing gap for some plate thicknesses and materials. The dynamic sealing gap is the change in sealing gap due to different operating conditions caused by shifting different gears. Now, the challenge is to find a gasket layout that can follow the deformations due to assembly and operating conditions. Further, the gasket has to provide enough sealing pressure in all working conditions to avoid leakage.

Example results matrix of different distance layer plates

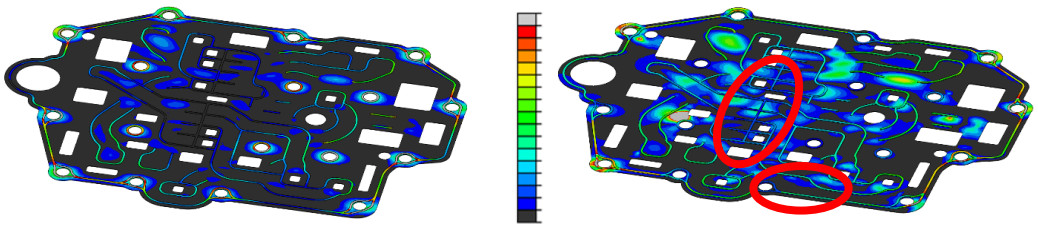
	STEEL			ALUMINUM		
PLATE THICKNESS	1,0 mm	2,0 mm	3,0 mm	1,0 mm	2,0 mm	3,0 mm
ASSEMBLY	0	0	0	0	0	0
GEAR_1	14,2	5,5	4,4	30,1	8,4	5,2
GEAR_2	1,8	1,9	1,9	2,8	1,7	1,7
GEAR_3	5,5	2,3	2,4	14,8	2,4	2,0
GEAR_4	3,1	1,5	1,5	9,0	1,5	1,4
BURST PRESSURE	17,8	8,2	7,2	35,6	11,0	7,7

Figure 11. Maximum change in sealing gap in µm for different plate thicknesses and materials

The application of a gasket to a new system is a process that has to deal with many issues like bolt load, deformations and sealing pressure. Abaqus® is supporting us to find the best solution for our customers in consensus with functionality, weight and cost.

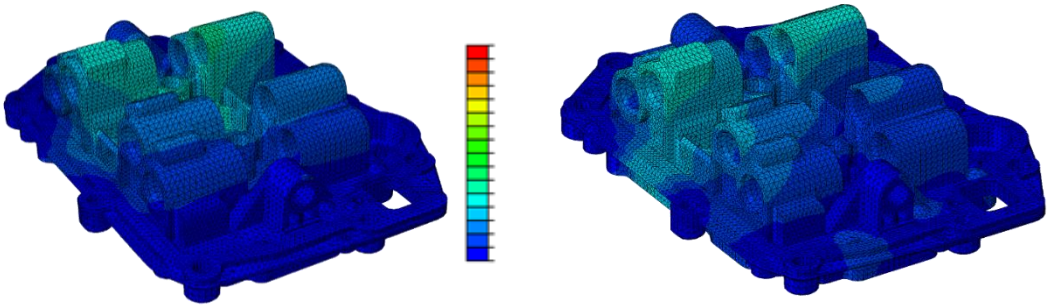
Comparison of the DANA® MLS separator plate with a conventional separator plate:

The DANA® MLS (multi-layer steel) separator plate has two outer layers of steel (a top layer and a bottom layer on each side of the distance layer) with stamped beads to seal the hydraulic channels. The distance layer adds stiffness to support the sealing function of the outer layers. Compared to conventional separator plates which use screen printed or molded rubber, or paper gasket, the DANA® MLS provides a much higher sealing performance and durability.



Conventional plate with pressure holes **DANA® MLS plate with sufficient sealing pressure**

Figure 12. Sealing pressure at working condition GEAR_1_3



Conventional plate with higher deformation **DANA® MLS plate with lower deformation**

Figure 13. Deformations at working condition GEAR_1_3

A typical 3D simulation runs on 12-48 cores and takes 1-2 days on a HPC cluster.

Sealing bead optimization:

The primary function of the bead in a gasket is to provide adequate sealing pressure while also providing adequate recovery due to the change in pressure. This can impact the durability of the bead long term. To achieve optimum bead stiffness and recovery, DOE studies were completed using ISight & Abaqus®. The objective of the study was to maximize the bead recovery based on various tool parameters used to create the bead shape. The bead was formed, subjected to load-unload cycles to measure recovery. Other factors studied include forming and assembly stresses in the bead for the range of tooling parameters.

A simple 2D axis-symmetric model was used in Abaqus®, with MS Excel® component used to change the tool design parameters. Output results were read from results file (.odb) by the Abaqus® component in ISight.

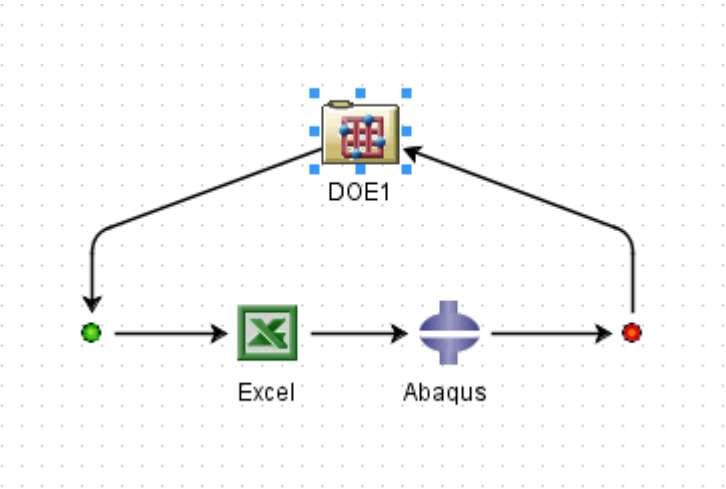


Figure 14. Optimization loop

Results

Figure 15. Contact pressure at full compression

Figure 16. Contact pressure at maximum unloading

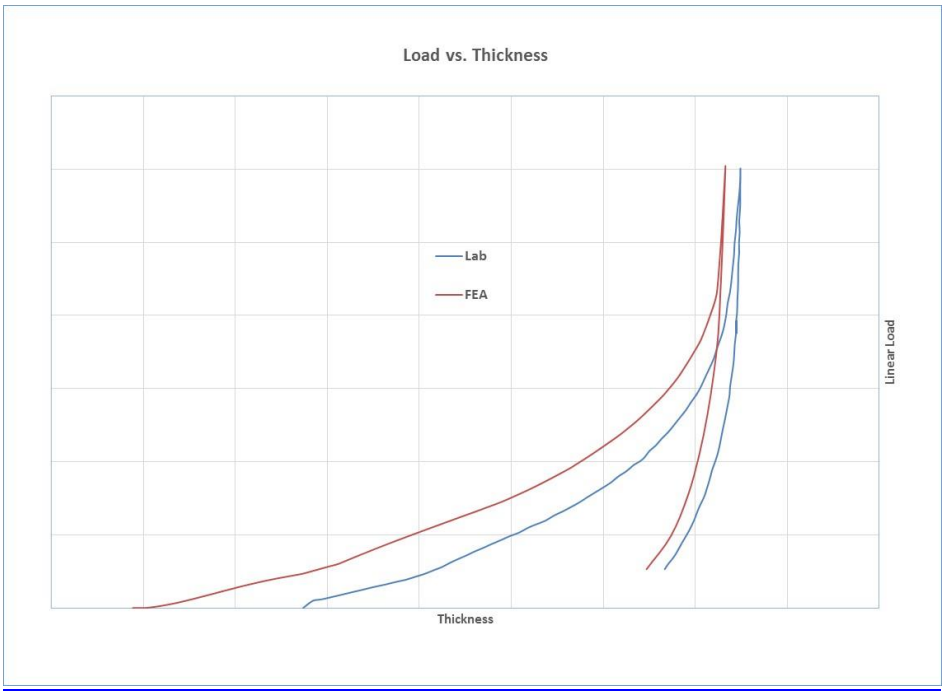


Figure 17. Comparison of load – unload curves between FEA and laboratory

Figure 18. Results of bead recovery vs. tool height

Results indicate that tool height is the factor that contributes most to the variance of the recovery of the sealing bead. The results from ISight study were checked with physical laboratory data for comparison. There seemed to be good correlation in the results between the Abaqus® predicted recovery and lab tested samples. The variation in the results were attributed to variation of the coating thickness which may have influence on friction between the sealing bead and the test plates.

g) Summary and conclusion

The teamwork of different development disciplines like CAD, FEA, testing, material research, brought up a new high performance sealing solution. As a part of the development Abaqus® enabled the team to understand the nature of transmission plates and thus brought the team in a position to improve and optimize the performance of the gasket.

The new DANA® partially coated multi-layer steel transmission plate meets the highest customer sealing requirements and is accepted by our key customers.