STATISTICAL APPROACH TO PREDICT SEALING PERFORMANCE

MANN+HUMMEL benefits from the use of optiSLang and its capability to develop increasingly cost competitive designs as an example for simulation driven product development.

Introduction

MANN+HUMMEL is a global leader and pioneers in filtration with a rich heritage and experience of more than 75 years in the business. Each second, 26 filters are produced, shipped, sold and installed worldwide. As a global player, MANN+HUMMEL understands the requirements and demands of the market, having its core business areas in automotive domain, industrial sector, intelligent air solution and water solutions.

Air filters in automobiles are an essential and integral component that prevents particles from entering the engine cylinder. When air filters are viewed as a system, there is the dirt side which is exposed to all the elements of the atmosphere, and then there is the clean side with filtered air, which later makes its way into the engine. In between these two stages, an effective form of sealing has to be present that prevents leakage of uncleaned air into the clean side of the filter. Thus sealing plays a crucial role in filtration and in turn engine life. Sealing is usually made of PU foams or elastomers, which are highly expensive. Hence the ultimate objective is to reduce the gasket volume by use of parametric modeling and by retaining adequate contact pressure with minimal mounting force that defines the sealing efficiency.

Methodology Approach

Focus of the article is to highlight the approach followed in the product life cycle. Hence for the purpose of representation, the air filter housing along with seal is simplified (Fig. 1). Sealing is considered as a gasket model where stiffness contribution in transverse direction is much smaller than the stiffness along the thickness. Clamps and hinges on the peripheral region compresses the gasket and provides adequate pressure to restrain leakage. Although the optimization of the housing and sealing profile can be combined together (Fig. 2) for a better discerning, both are addressed separately.

Seal profile optimization

Parametric Model

Seal profile optimization is carried out using 2-D sectional analysis. A parametric model of the seal is created within the given design space and constraints (Fig. 3). Parameters and their ranges are set based on the past product experience and manufacturing feasibility.

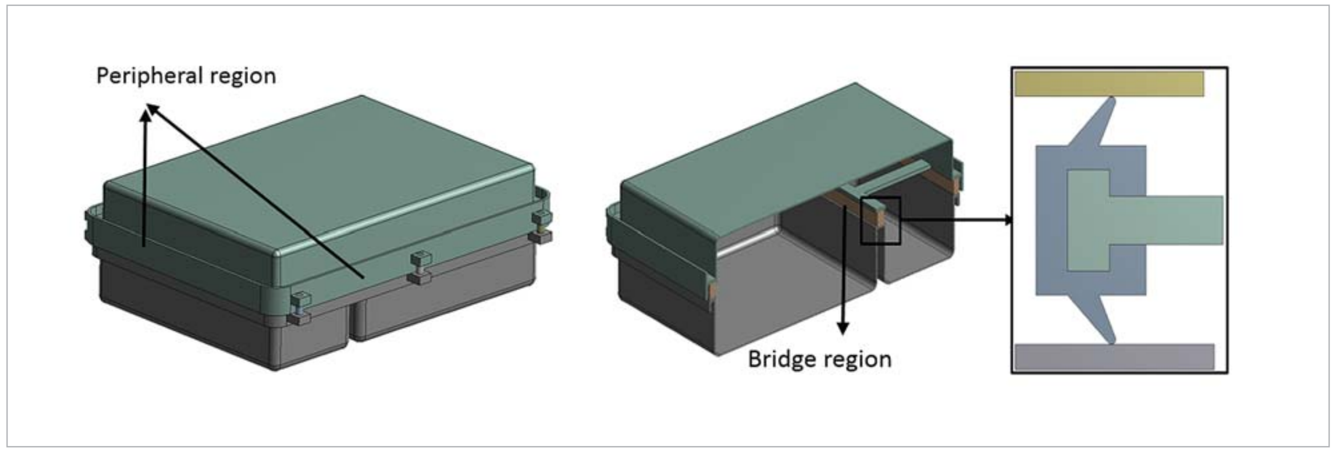


Fig. 1: Simplified Model of Air Filter with seal profile (reference model)

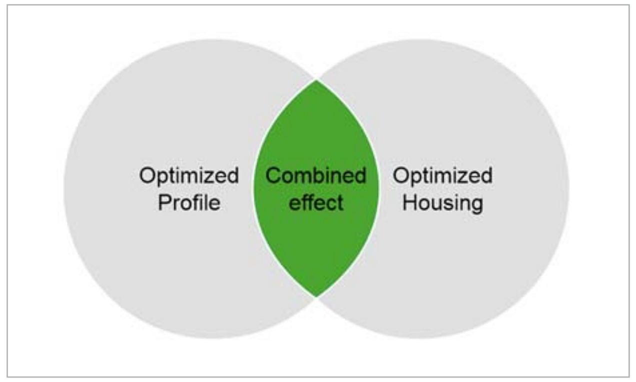
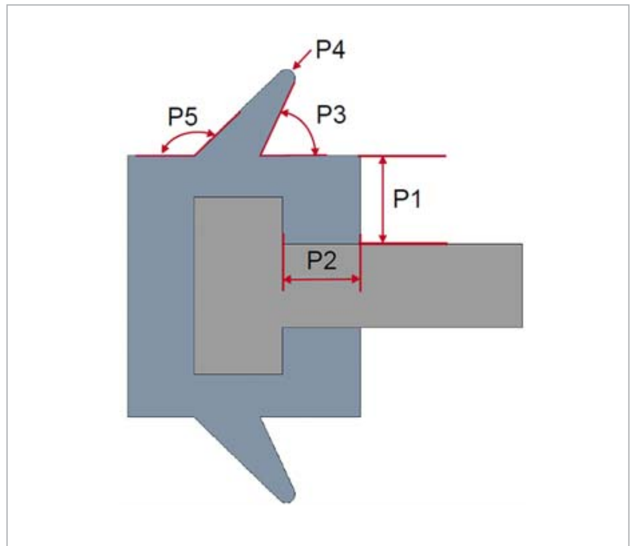


Fig. 2: Schematic representation of the approach



Parameter	Name	Range
P1	Height	Nominal ± 10%
P2	Width	Nominal ± 20%
P3	Angle 1	Nominal ± 15%
P4	Radius	Nominal ± 12%
P5	Angle 2	Nominal ± 13%

Fig. 3: Parameters and their range for seal profile optimization (reference model)

Boundary Conditions

Air filters are mounted in close vicinity of engines and are exposed to elevated temperatures. Roping in this fact, the analysis is carried out at high temperature. Gasket is assigned with ShoreA hardness and the frame inside the gasket with plastic respectively. Casing is fixed and seal is compressed with the cover to replicate the assembled condition (Fig. 4). Contact pressure, mounting force and volume are the important output parameters which are contemplated in order to achieve the optimized design.

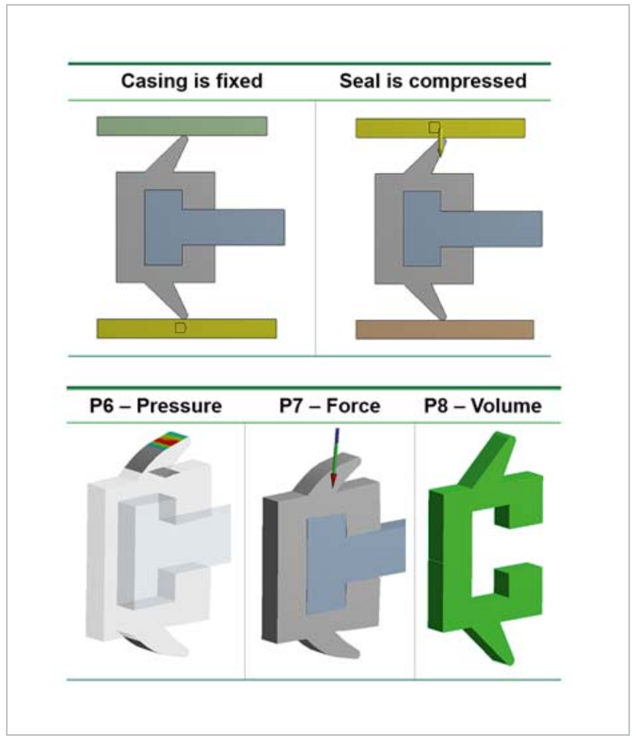


Fig. 4: Boundary conditions and output parameter (reference model)

Sensitivity Analysis

Sensitivity analysis is carried out to determine the major influencing parameters on the required output parameter. A large number of well laid out design points are employed to

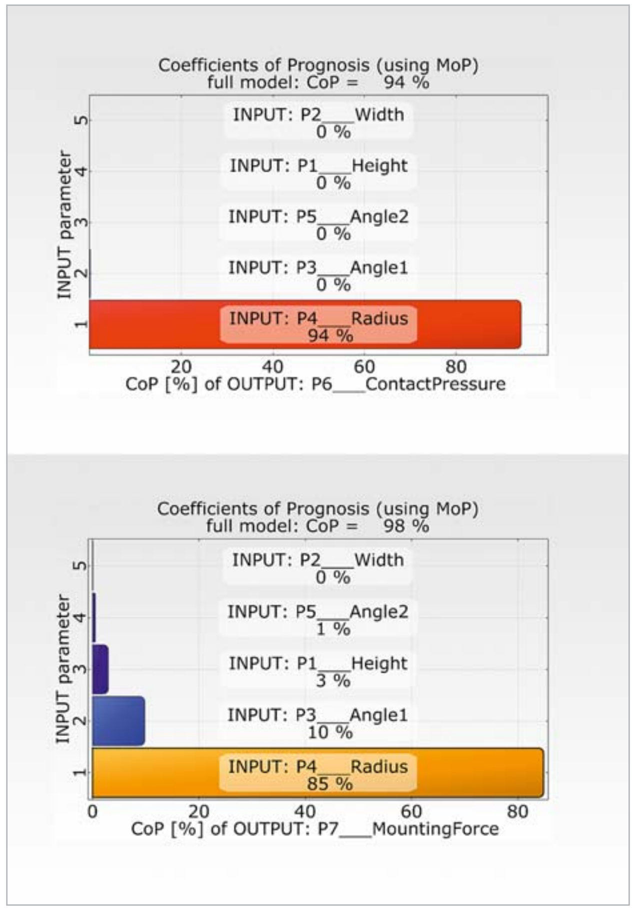


Fig. 5: CoP for contact pressure and mounting force

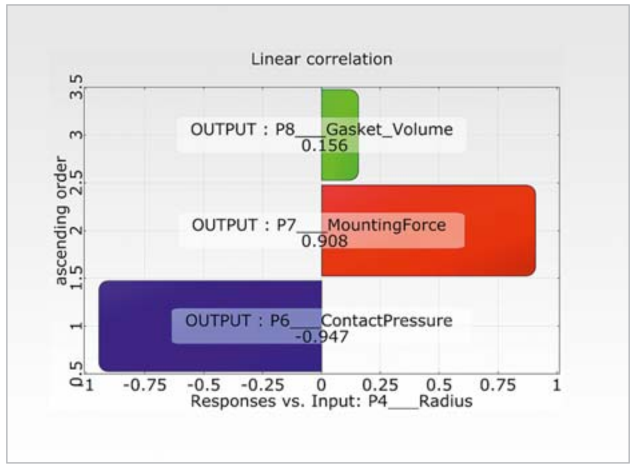


Fig. 6: Linear correlation for radius

capture the domain precisely using advanced Latin Hypercube Sampling method. Coefficient of Prognosis (CoP) for contact pressure and mounting force remains stable with radius being the major influencing parameter (Fig. 5). The parameter "P3 - Angle1" also contributes to mounting force to a certain extent. The linear correlation plot (Fig. 6) indicates that the increase in radius, decreases the contact pressure, increases the mounting force and gasket volume. With a robust CoP value as the primary quality measure, the outcome of sensitivity analysis is taken further into optimization.

Optimization

Optimization is performed to single out the best possible design within the given design constraints. Evolutionary algorithm is used for the same, as it provides added advantage of multiple constraints and objectives. Optimal contact pressure is necessary to prevent gasket leakage with the lowest mounting force for the safety of adjacent component during assembly. Minimizing the gasket volume to save on material cost, is an additional objective for optimization. Evolutionary algorithm estimates all possible input parameters to achieve exceedingly superior results (Fig. 7):

- Optimal contact pressure
- Reduced mounting force
- Minimized gasket volume

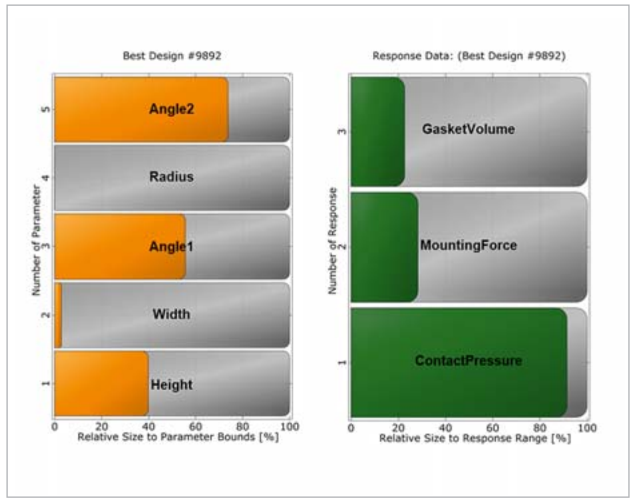


Fig. 7: Objectives, best input parameter and best output parameter

Cross Validation

With the best design parameters, a CAD model is constructed. Simulation is run with the same boundary conditions and material properties to cross validate the output from optimization. Difference between statistics and simulation (Fig. 8) was found to be within acceptable limits suggesting precise correlation.

Output	Difference	Checklist
Contact pressure	3%	☑
Mounting force	1.2%	☑
Gasket volume	0,8%	☑

Fig. 8: Difference between statistics and simulation

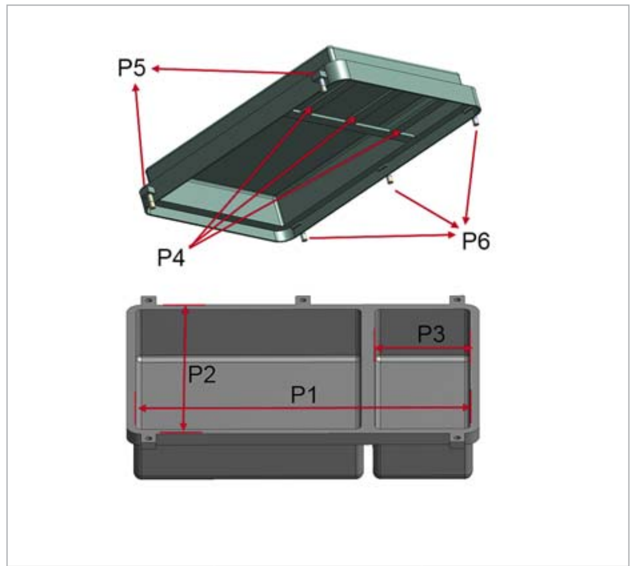
Results

Comparing nominal design with that of the optimized, the contact pressure and mounting force was the same but the gasket volume was reduced significantly by 13 %. In such cases, a balance has to be struck by drawing a line whether to have a certain sealing efficiency with corresponding gasket volume.

Housing optimization

Parametric Model

Parametric model of the housing is constructed based on the design space provided by customer. The entire parametric model is built from scratch using the ANSYS Design Modeler software. In all, about six parameters are singled out, of which three parameters have continuous range and three are scalar numbers (Fig. 9).



Parameter	Name	Range
P1	Length 1	Nominal ± 30%
P2	Width	Nominal ± 20%
P3	Length 2	Nominal ± 25%
P4	Supports	Nominal ± 3
P5	Clamp 1	Nominal ± 1
P6	Clamp 2	Nominal ± 1

Fig. 9: Parameters and their range for seal profile optimization (reference model)

Gasket Modelling

Seal is modeled as gasket with INTER195 elements having eight nodes and three translation degrees of freedom at each node. Considering the actual seal profile in the housing model for simulation results in element distortion with unusually long run times, rendering is infeasible. Hence gasket modeling is always more reliable, with swift turnaround times in parametric study. Closure versus pressure curve is obtained from sectional analysis carried out on the optimized seal profile (Fig. 10).

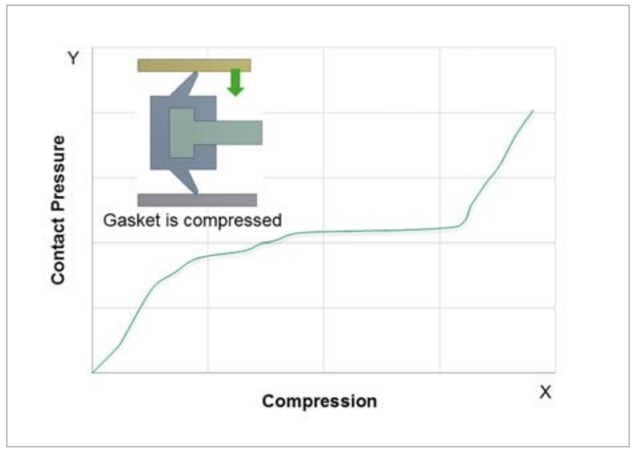


Fig. 10: Closure versus pressure curve (reference model)

Boundary Condition

Boundary condition for static analysis is imposed by fixing the housing and applying bolt torque at the clamp/hinge location. Normal gasket compression and pressure is considered as output from the analysis. When closely observed (Fig. 11), gasket compression and gasket pressure is adequate along the periphery but lower in the bridge region that is region responsible for separating the clean and dirt sides of the filter. Hence pressure in bridge region is of paramount importance, because it directly dictates the sealing efficiency of the whole filter.

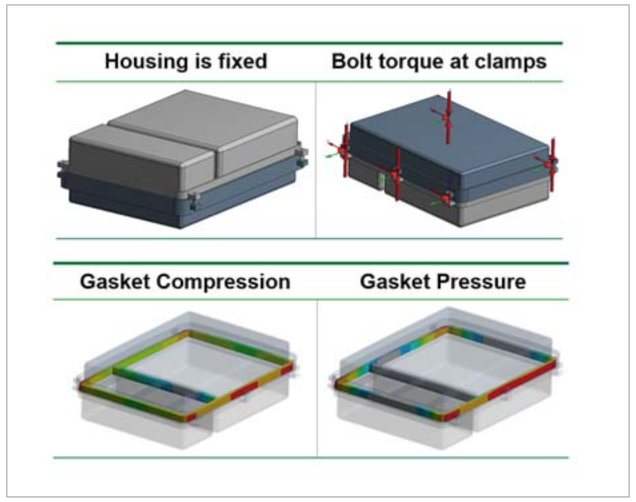


Fig. 11: Boundary conditions, gasket compression and gasket pressure

Sensitivity Analysis

The sensitivity analysis is executed within the given range of the parameters until CoP attains a stable value. Width and length2 are the influencing parameters in determining gasket pressure at the bridge region (Fig. 12, see next page). The pressure distribution graph (Fig. 13, see next page) aids designers in estimating the behavior of pressure distribution for a similar kind of model, hence enhancing the product design very early in the initial phase.

Gasket Pressure Distribution in bridge region

The background color (Fig. 13) represents the gasket pressure distribution in bridge region, while the major influencing parameters, width and length2 are X and Y axis respectively. Isoline represents minimum required pressure at the bridge region and is set as per the design specification. In this case, as a reference, it is set to 100 mbar. To meet the required contact pressure, X and Y coordinates, lying on the left of the line, are to be chosen. The X and Y coordinates in the upper right corner of the plot indicate the low pressure region.

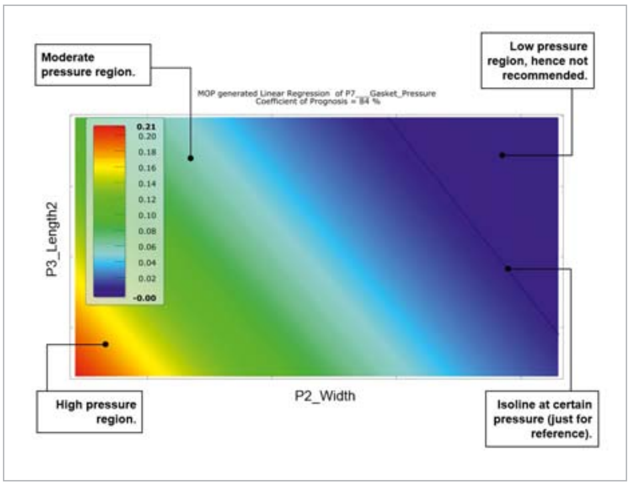


Fig. 13: Pressure distribution on bridge region

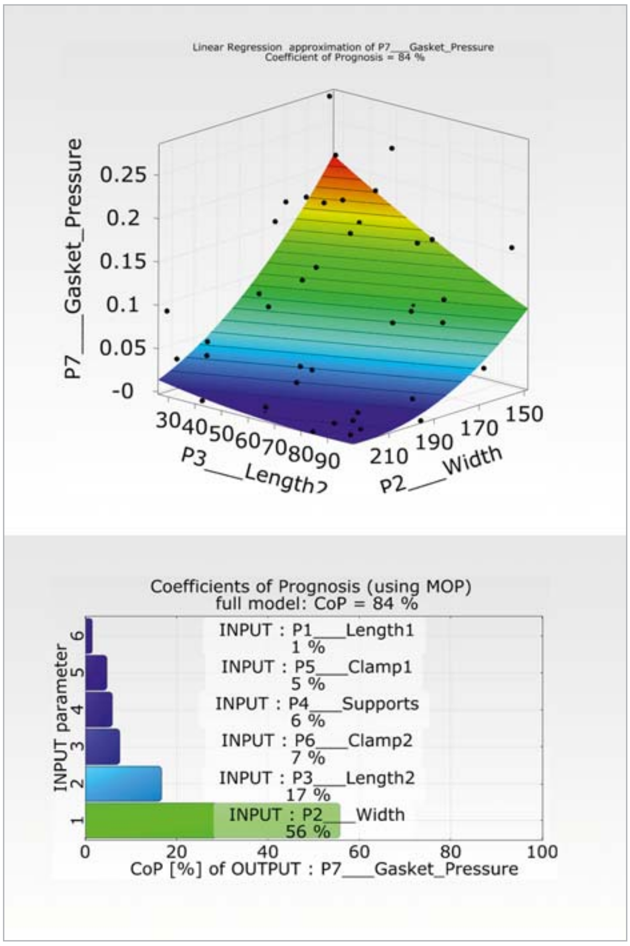


Fig. 12: MOP and CoP for gasket pressure

Excel MOP

In addition to pressure distribution plot, the excel MOP is handed over to the designers in order to derive the exact value of pressure with changes in the input parameter (Fig. 14). To start with, the MOP solver has to be installed in excel and then input parameters can be varied within the advised range. Afterward, the *.bin file obtained from sensitivity analysis is loaded into the MOP solver and initiated. Since the behavior of results outside of the range cannot be predicted, extrapolation is discouraged.

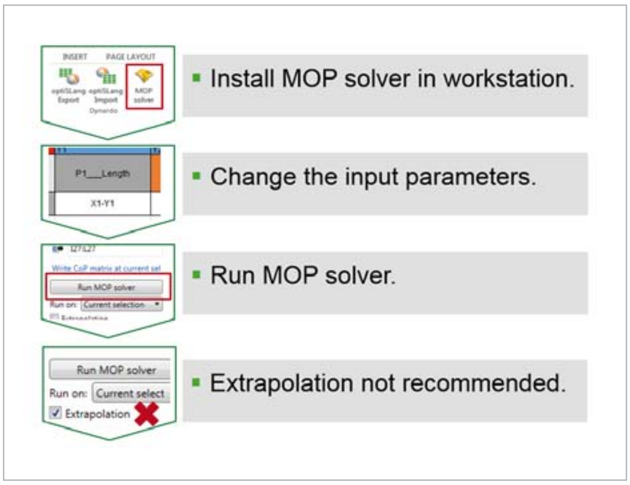


Fig. 14: Steps to use excel MOP

Conclusion

- Simulation coupled with statistics is employed early in the design phase of an air filter. This raises the bar as a classic example of simulation driven product development project resulting in reduced lead time, increased quality and reduced development costs.
- Gasket volume is lowered by 13 % for the same mounting force and contact pressure, leading to savings in material
- Width and length2 are the influencing parameters on gasket pressure in the bridge region. Optimization of the complete assembly further enhances the performance of the air filter.
- Combined effect of optimizing the housing and profile may yield an optimized assembly and serve as an outlook of the current studies.

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