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AUTOMOTIVE BONNET HINGES SHAPE OPTIMISATION USING LINEAR FE SIMULATION & COMPARATIVE METHOD

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ABSTRACT
Among main characteristics, requiered for mechanical assemblies, respectively for automotive Bonnet Hinges (in the remaining text BH) too, is stiffness. If the assembly do not fulfill stiffness requirements it is necessary to optimize it's shape. FE stress and strain simulations (in the remaining text FEA) for individual parts or assemblies are widelly used. FEA should simulate eather real load conditions (if possible), eather load conditions aplied during lab.-testing (wich is much more often situation in automotive industry). FEAs are shortening shape optimisation duration, but if one tries to achieve absolutely credible simulation of phisical load condition, FEA can be relatively long lasting, too. In the present paper examle is shown, where as great as possible, but still reasonably acceptable simplifications for FEA have been used, combined with simple comparative method, where BH shape optimization process duration is maximaly shortened. Optimization goal was to improve BH stiffness under loads aplied, when Bonnet is subjected to turbolent air flow, caused by large vechicle velocities (over 200 km/h)).
Keywords: Bonnet Hinges, wind-tunell test, FE simulation, FEA optimization, stiffness.

1. INTRODUCTION
When performing FE stress and strain simulations (FEA) for mechanical assemblies, built from various materials, one face a problem to simulate their behaviour during deformation, and even to simulate their condition after assembling process. One of such assemblies is automotive Bonnet Hinge (BH). These effects are more significant when BHs are built with more levers and pivot points.

Figure 1: Bushing assembled on Lever

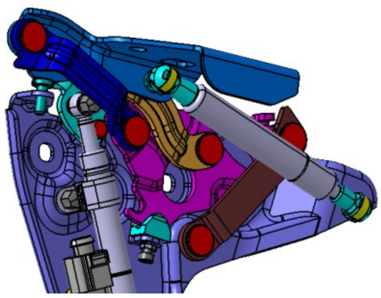


Figure 2: Examined BH - Initial design

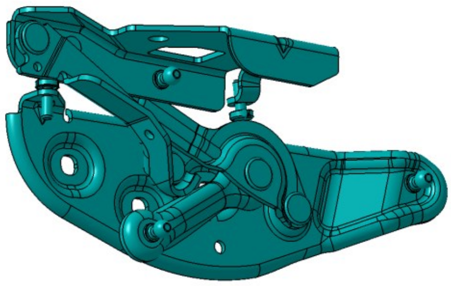


Figure 3: BH – without Pedestrian Protection System

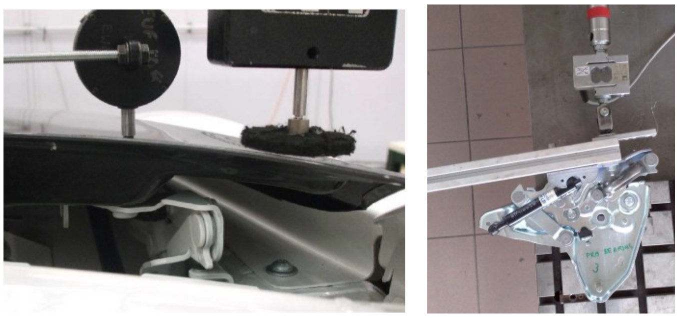
BH Levers are comonaly metal (in examined case steel). BH pivot points are made using combination of Rivets and Bushings (Figure 1), made from various composites (steel plate/Teflon, brass mesh/Teflon, etc.). These materials have different elasto-plastic properties. Additionally, during assembling Bushing is deformed, where deformation varies, because assembling is performance adjusted. During assembling BHs are connected on the Bonnet and then on the Car body. Afterwards, Gas Springs are connected to Bonnet and Car body, then Bonnet stiffness is adjusted by adjusting BHs Adjustment screws. Gas Springs function is to optimize hand-force during opening and closing of the Bonnet, but their force influencing Bonnet stiffness too.

For these reasons precise FEA for assemblies described above, such are BHs with large number of Levers and pivots, is complex and long-lasting to prepare and to perform. It has to be performed by non-linear solver, with special boundary conditions. However, even by using non-linear solver it is difficult to obtain high accuracy results.

This paper describes an example of fast performed BHs (Figure 2) shape optimization, utilizing FEA in linear solver Elfini, combined with simple comparative analysis. Shape optimization is performed with goal to improve the stiffness of Car Bonnet at high driving velocities. At high velocities, air flow on the Bonnet becomes turbulent creating varying vacuum on the Bonnet surface, which results with forces puling Bonnet upwards, deforming BHs/Bonnet, therefore Bonnet is oscillating in the vertical direction. If BHs are not stiff enough, these oscillations can cause small damages of Car body, and become noticeable to the Car driver, causing sense of discomfort, as well.

BH examined, is a version with integrated Active Pedestrian Safety System (Figure 2). On the same Car body, for different markets, BHs without Pedestrian Safety System (Figure 3) are assembled, too. This two Car bodies, with different BHs, have been tested in the Wind-tunnel, where version without Pedestrian Safety System had satisfactory stiffness, and version with Pedestrian Safety System did not. Reason is different kinematics and additional Levers, which decreases active BHs stiffness.

2. EKSPERIMENTAL WORK



a) b)

Figure 4: Z-direction deformation measurement: a) on the Car body, b) on the Test-rack

Regarding test in the Wind-tunnel is long-lasting to prepare, unavailable on all locations, and expensive; for preliminary stiffness tests simplified method is utilized, where (Figure 4):

- Pair of BHs are connected to Car body (or specialized Test-rack) and Bonnet (or specially adopted frame),
- Assembly is pretensioned using Adjustment Screws,
- Appropriate test forces (dragging and compressing) are applied on the Bonnet, and displacement of rear-end of the bonnet is measured.

Stiffness of BHs, with and without Pedestrian Safety System, has been tested by this method too, and same conclusions were drawn as with Wind-tunnel test.

This testing method is much more suitable for FEA, and therefore used. However, if one insist to perform completely faithful FEA, even for this simplified test, it is going to be long lasting to prepare and perform, for above described reasons. To minimize FEA duration, following procedure was adopted:

- Drag load in the Z-direction, have been chosen as more significant.
- Regarding each design is going to be validated using comparative method it is chosen that applied Load in the FEA will be double of the test force. Double Load is used to validate strength of the construction simultaneously (stresses).
- Displacement of the Initial BH design (design with the Pedestrian Safety System, which had an insufficient stiffness) was taken as a referent value. When system was tested with the drag-force, on the Car body, vertical movement of the Bonnet rear-end was 3,44mm, where allowed value is 2,1mm. Comparing this two values, it is concluded that tested BH stiffness, should be increased for ~64%, (BH deformation, when tested, should be decreased for ~39%).
- As most influencing BH stiffness, Short Connection Lever was detected.
- Short Connection Lever shape variation was performed, where for each variation FEA was performed.
- BH displacement value readings, for each variation, were compared with the referent value.
- Version with smallest reading, with reasonable workability, was chosen as an optimal version.

Figure 5 shows simplified FEA setup, where main characteristics are:

- FE mesh with 3D elements was created only for BH Levers.
- Pivot points were simulated with 1D ″rigid-spring-rigid″ elements, with allowed rotation around chosen axis.

- BH connection with Car body was simulated by fixing (restricting movements in all directions) all nodes on internal surfaces of the connection holes on the BH Fix-Lever.
- Bonnet was simulated using absolutely stiff 1D elements, rigidly fixed to BH Mobile-Lever. Bonnet connection with the Front-lock was simulated by movement restrictions in Y and Z –axis direction; defined in two points, to prevent rotation of the 1D elements around Z-axis.
- Load was applied on connection points between Bonnet and Mobile Lever, in the Z-axis direction, upwards. Gas Spring, and Adjustment Screws force influence was neglected.

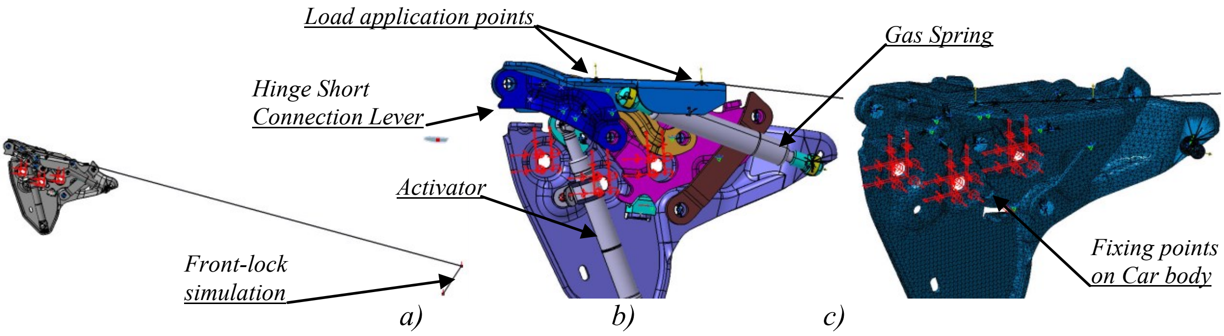


Figure 5: FE model: a) complete, b) Shown on Hinge CAD model, c) FE mesh

3. RESULTS AND DISCUSION

FEA results (strain and stress), for BHs Initial design, are shown on Figure 6. Maximal displacement read on the BH was 15.0mm, where displacement component in the Z-axis direction was 13,7mm. Comparing this readings with physical test results, and displacement allowed value, BH displacement goal value in the Z-axis direction was calculated: 13,7mm/1,64=8,36mm.

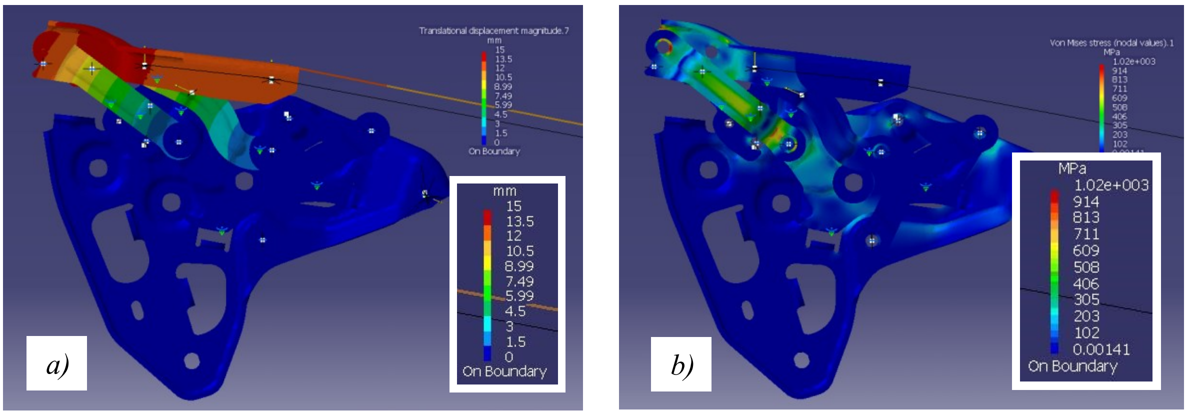


Figure 6: BH with Active Pedestrian System –Initial design: a) Strains, b) Stresses

After BH displacement goal value was calculated, BH Short Connection Lever shape was varied and FEA has been performed, for each version. When various versions of Short Connection Lever were designed, two criteria have been taken in account:

- Space available (in closed position, opened position, and all possible Bonnet movements).
- Workability (Short Connection Lever should be suitable for stamping production process).

In the Table 1 BHs FEA displacement readings are displayed, for designs with different Short Connection Lever; and Figure 7 displays several characteristic shapes.

From Table 1 is visible that versions 14 and 15 resulting with BH best stiffness. Version 14 was taken with some precaution, because it should be first deformed, and then cut to produce, which was different then previous production concept (part was Laser-cut, and then deformed; because of small production quantity). For this reason for further proceeding and Prototype production version 15 have been chosen. It was expected that part stiffness at physical testing will be bit better than one predicted by FEA and comparative method (8,66mm*2,1mm/8,36mm=2,18mm), taking in account Gas spring influence, which is smaller if BH design is stiffer.

After Prototypes were produced, with Short Connection Lever version 15, and tested with drag force in the Z-direction (Figure 4b), measured displacement was 1,97mm, which have been satisfactory (<2,1mm). Prototype stiffness in the Wind-tunnel test has been satisfactory, as well.

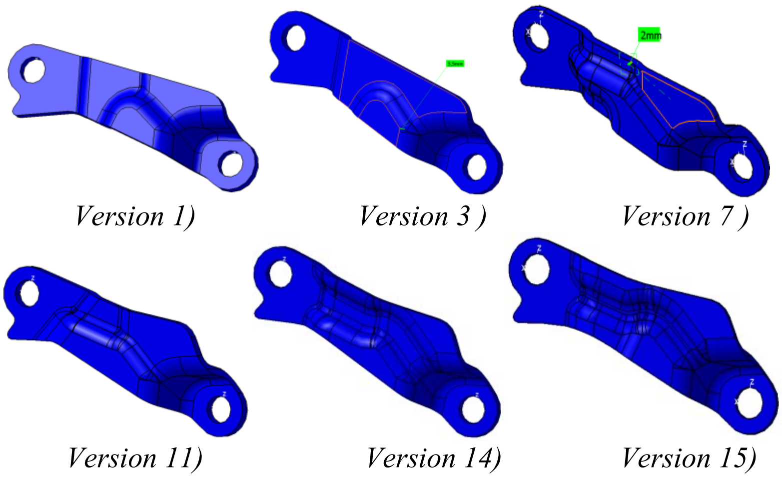


Figure 6: Several characteristic Short Connection Lever shapes

Table 1: Hinge displacement with different Short Connection Lever shapes

Version	1	2	3	4
ΔL	9,94	10,5	10,3	11,3
ΔL_Z	9,02	9,54	9,35	10,2
Version	7	8	11	12
ΔL	10,6	10,7	10,9	10,8
ΔL_Z	9,58	9,68	9,87	9,84
Version	13	14	15	16
ΔL	10,9	8,89	9,48	9,87
ΔL_Z	9,92	8,11	8,66	9,01

ΔL - Hinge displacement
ΔL_Z - Displ. in the Z-

4. CONCLUSION

Practice has proved that, for most mechanical assemblies, it is possible to perform FEA which faithfully simulates their behaviour, under external loads influence. This significantly shortens shape optimization processes. However, sometimes faithful FEA, last longer than we can afford. In the examined example, FEA has been set with significant simplifications, which have multiply shortened simulation duration. Time saving effect is bigger because FEA has been performed 16 times. Simplifications have been carefully chosen with goal to have impute errors approximately proportional to result. This way it was possible to compare FEA results with Initial BH design displacement, and using simple comparative method predict real displacement for different design versions. For the design chosen as optimal, by FEA and comparative method 2,18mm displacement was predicted, where displacement measured afterwards on physical test was 1,97mm. Measured displacement deviation from predicted value has been very small, and it satisfied requirement (2,1mm). This shows that by using maximally reasonable simplifications, and simple comparative method it is possible to multiply decrease duration for automotive BHs shape optimization process.

5. LITERATURE

[1] S. Dogan, C. Guven, F. Karpet. T. G. Yilmaz, O. Dogan: Experimental Verification and Finite Element Analysis of Automotive Door Hinge , ASME 2014 International Mechanical Engineering Congress and Exposition, Volume 11:Systems, Design and Complexity, Montreal, Canada,2014.
[2] N.D.More, T.A.Jadhav: Stress Analysis and Optimization of Car Door Hinge, International Engineering Research Journal, June 2016.
[3] T. G. Yılmaz, M. Tüfekçi , F. Karpat: A Study of Lightweight Door Hinges of Commercial Vehicles Using Aluminum Instead of Steel for Sustainable Transportation, Sustainability - Open Access Journal, MDPI, Basel, Switzerland, 2017.
[4] Y. Yang, E. S. Jeon: Tailgate Hinge Stiffness Design using Topology Optimization, International Journal of Applied Engineering Research,Volume 11, Research India Publications, 2016.
[5] A. Govik: Finite Element Analysis of Sheet Metal Assemblies - Prediction of Product Performance Considering the Manufacturing Process, Linkoping University, Sweden, 2014.