Simulation of Vehicle Headlamp Levelling systems

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Abstract

Adjustment systems are used in vehicle headlamps to regulate the flare on the street. The kinematic system within the headlamp is driven automatically based on level sensor signals and can additionally be manually set to a start position. In modern cars the automatic vehicle headlamp levelling is legal duty due to the strong *cut-off line (COL)* between dark and light. This COL can be measured in a workshop but not during operation. Due to the complex kinematics including nonlinear contacts, friction and damping a Modelica model is used to calculate the position of the *COL*. The results show a characteristic hysteresis of the horizonal position during automatic movement. The simulation results are compared to measurements and show good agreement.

Keywords: Cut-off line, hysteresis, headlamp

1 Introduction

Modern vehicle headlamps have a strong *COL* between dark and light. Different loads can cause oncoming traffic to be blinded unintentionally (Hignett 1970). To prevent that a vehicle headlamp levelling system adjusts the *COL* based on information of level sensors at the car axles. The mechanical system to adjust the horizontal or vertical position of the *COL* is strongly nonlinear because of contacts, friction, elasticity and damping such that a hysteresis behavior of the *COL* position vs. the adjustment size can be observed (Opgen-Rhein et al. 2004).

Overall hysteresis can be defined as a difference between the direction of a process which changes the system. In our case this process is a levelling of the COL, and the direction of movement can lead to different ending position of COL. Thus, the hysteresis behavior can be considered as parasitic.

The aim of this paper is to model the dynamics of the levelling system to understand the origin of hysteresis and to predict the position in detail anytime. The model is used in early predevelopment phase of few headlamp projects to verify design ideas and optimize the adjusting system. In this work the model is described and validated with measured data of a real headlamp.

2 Hysteresis behavior of Vehicle Headlamp Levelling

As hysteresis in a headlamp levelling system, we define the difference between start and end position of COL after a defined levelling process. Each automotive company have different measurement processes, but principally it is always forward and backward (or exactly in opposite order) movement. Thus, we compare starting position of COL assuming as 0 and the end position as *h*. The distance between headlamp and wall on which is the COL projected is 10m. The position of the COL is measured in a special testing lab with adequate equipment. The COL level is digitally evaluated while the leveling is done by stepper motor connected to the adjusting system.
Each automotive company has special requirements about the COL level which should be kept. This prevents the unwanted position of the light on the street based on dynamic leveling during travel. The range of vertical (horizontal) COL travel varies but, in all cases, is smaller than 5°, in the 10 m distance equals to 0.87 m. Hysteresis in such a system can be significant and without proper focus on result will not fulfill the requirements. To prevent that the simulating model is created. The Modelica environment is chosen because of its multi domain capabilities because in these systems there are several physical phenomena.

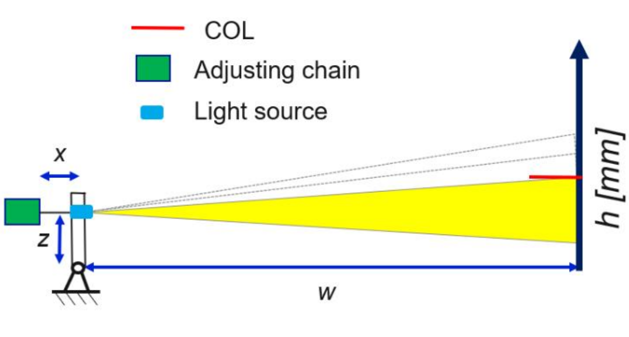


Figure 1 Vertical hysteresis test scheme

3 Modelica Model

The geometry of the hysteresis test shown in **Figure 1** leads to

$$h = x \cdot \frac{w}{z} \quad (1)$$

$$h = w \cdot \tan \varphi \quad (2)$$

where φ is the angle of rotation of the light source.

Geometry of most of headlamps is within following limits: z = 90…130 mm, x= 2…10 mm. Based on that we realize that any movement in x will lead to around 100 times bigger movement of COL in h. To create a model which is able to simulate such a system we need to pay attention to the adjusting system and include the following:

- Geometry of each part
- Backlashes between parts
- Elasticity of parts
- Contact deformations between parts
- Forces and friction in the system

The adjustment system is designed with several mechanical parts which are connected to each other. The adjustment can be done with an electrical stepper motor and by a manual rotational movement of the so-called customer interface which lead to mechanical movement of the whole adjustment system with stepper motor including. The Hysteresis test is done separately for both versions, but the system is connected as one. As it was written before this system contains several parts and each connection can generate unknown hysteresis behavior. From physical point of view, we can observe the following behavior on an example connection of 2 parts:

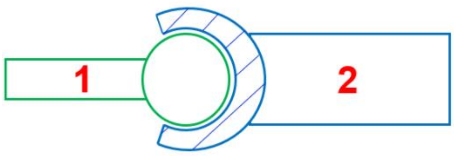


Figure 2 Connection of part1 and 2 in adjustment system

Then the hysteresis contribution of such a contact can be defined as:

$$h = h_b + h_d + h_e \quad (3)$$

Where:

h is total hysteresis

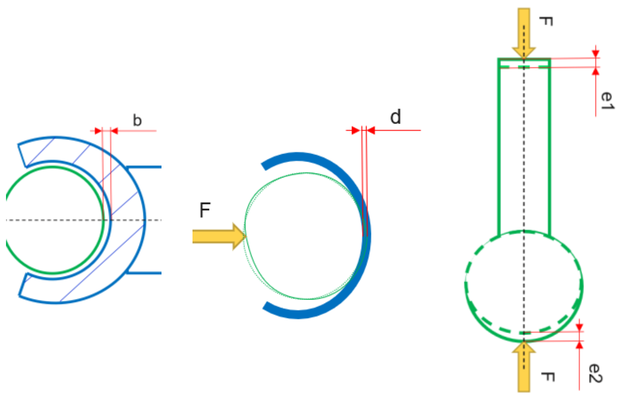
h_b is backlash part of hysteresis

h_d is part of hysteresis caused by deformation

h_e is elasticity part of hysteresis

Backlash	**Contact def.**	**Elasticity**
$\Delta h_b = b$	$\Delta h_d = d = (\frac{9F^2}{16E^2R})^{\frac{1}{3}}$	$\Delta h_e = e = \frac{F}{E \cdot S} \cdot l_0$

(Popov et al., 2019)



Δh_b= 0.001 mm	Δh_d= 0.008 mm	$\Delta\, h_e$= 0.0025 mm

$$h = h_b + h_d + h_e = 0.0115 \approx \mathbf{1.15\ mm}$$

Figure 3 Example hysteresis contribution with backlash, contact and elasticity.

In Figure 3 the contributions of each physical part shown in Figure 2 of the total hysteresis are shown. The radius of the ball is R and S is the area. Young's modulus is referred to as E. This particular example shows that the backlash does not have to be the main contributor to the hysteresis even thought that it usually is. The part of Figure 3 describing contact deformation includes manufacturing tolerances and imperfections of the production. Such a contact can be described by the Hertzian contact deformation law or a variation of it. The elasticity of parts contributes as well, due to the different orientation of internal force during leveling. This could be described by Hooke’s law. Hertzian deformation and elastic deformations depend on internal forces in the system. The tangential internal forces are functions of the frictions between elements in the system. Therefore, the problem of hysteresis contribution is pretty complex and needs to be simulated. Some factors can be simplified by linearization of the behavior.

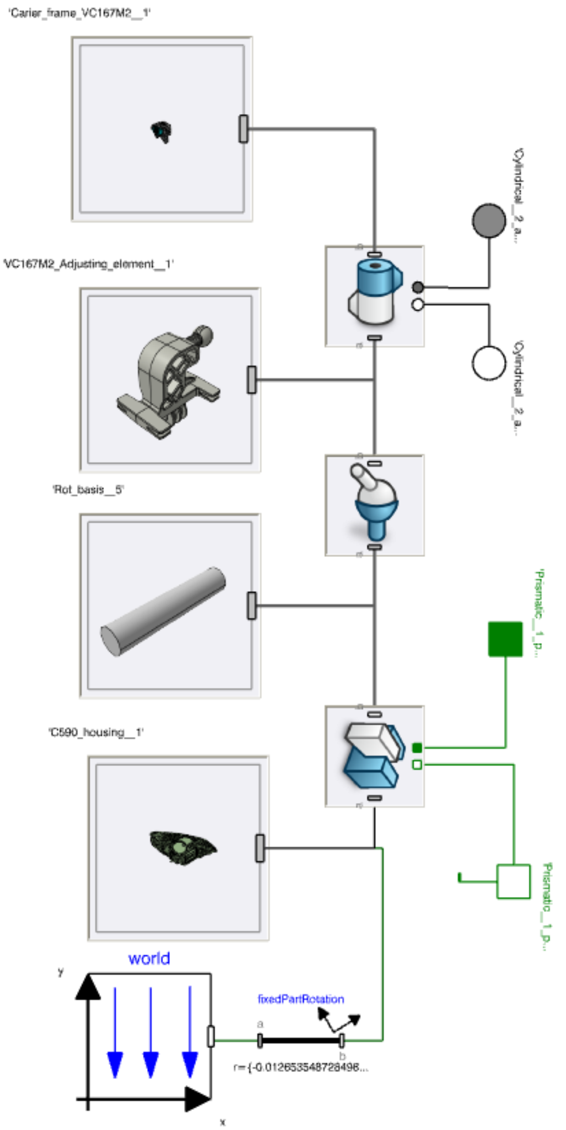


Figure 4 Basic kinematics scheme created in 3DExperience

To create a Modelica model capable of simulating the hysteresis of a COL during the development of a headlamp the software Dymola 2022x and Behavioral modeling (Dymola) in 3DExperience 2022x platform from Dassault systems are used. Very useful is a CATIA interface for kinematics. The kinematics can be easily defined in CATIA. In the next step a Modelica model can be automatically generated with 3DExperience. This Modelica model is based on the precise geometric parameters of the system, such as geometry, center of gravity, inertia tensors and mass of the body. It can be used within 3DExperience or exported to Dymola without loss of functions.

Figure 4 shows a part of subsystem of the main body of a headlamp and its adjusting system. Parts are connected through joints. Controlled joints need to be connected to other subsystems which define their behaviors in terms of torques, forces, elasticities, or backlashes.

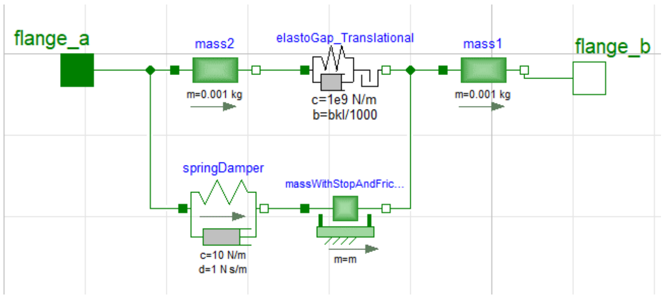


Figure 5 Subsystem of backlash with friction and hard stop

To model friction the subsystem in Figure 5 is used. It is a model with Stribeck characteristic, which is the most accurate and proven technique to simulate friction in mechanical systems. It combines static friction which is higher than the dynamic friction, when parts are moving. In addition, velocity dependency is included into this behavior. Thus, in comparison to a very simple Coulomb model of friction, this model can simulate more precisely parts which are sliding in guiderail. The behavior of that part is very dependent on friction. The Stribeck characteristic is described in Figure 6.

4 Simulation Results

The simulation model shown in the previous chapter was used in development of several headlamps. In the variety of projects, the design team is forced to use different adjustment systems. Some parts are changed due to space management but as the simulation model is developed as a parametric model, it is possible to adjust it to the current design. The simulation procedure is set up with the same parameters as the one in the measuring laboratory for every project. A big advantage of the model is that additional parameters like forces inside the system or input torques are tracked automatically.

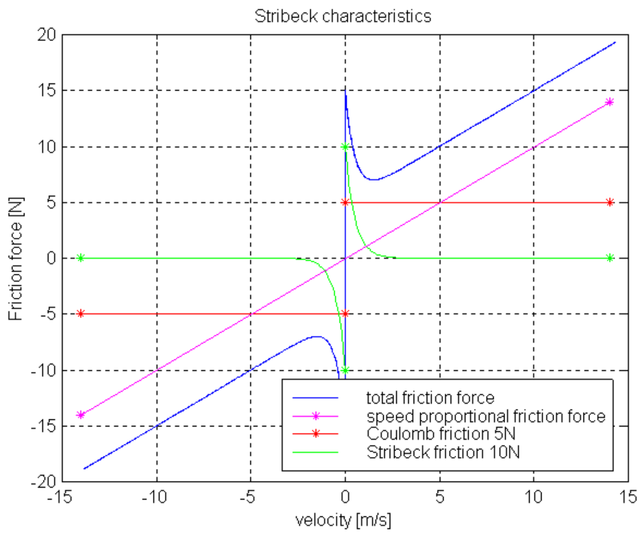


Figure 6 Friction definition using Stribeck characteristic

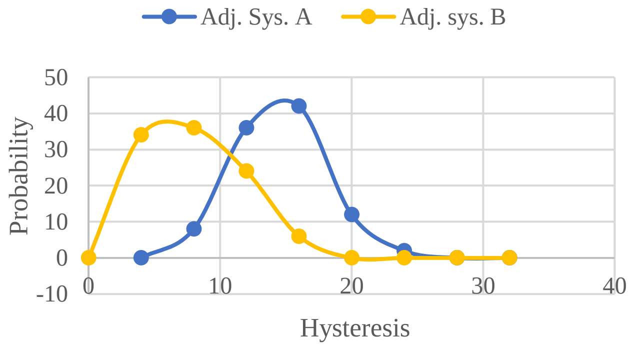


Figure 7 Hysteresis results histogram of 2 adjusting systems

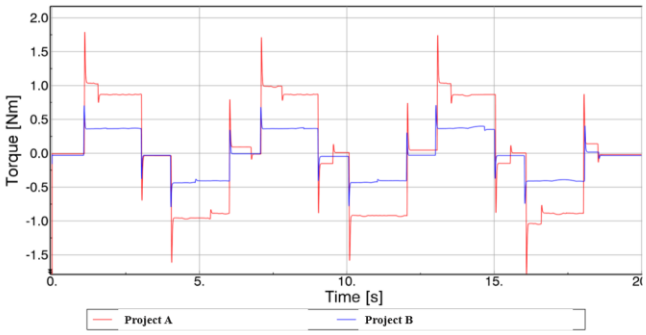


Figure 8 Driving torque needed to level during hysteresis test – project compared

Because of the high number of parameters and their manufacturing tolerances there is a need to perform hundreds or thousands of simulations during the design phase (Brück et al., 2002). A Monte Carlo approach was applied to include statistical characteristic of that problem. The simulation is run 500 times with randomly selected parameters. The distributions are chosen based on knowledge of tolerances and measured real production samples. The results can predict the possibility of a hysteresis test fulfilling requirements with current design. Example of results of two different adjusting systems used in headlamps are shown in Figure *7*. The difference between A and B Adjusting systems are in the design and the parts are used. Due to restricted space inside of a headlamp the A system is smaller and less robust. This is why his behavior leads to worse hysteresis results.

In Figure 8 two torque characteristics are shown. It is a comparison of two different projects. It can be observed that Project A is dealing with way more higher torque values. This can lead into problems within the adjusting system and the design needs to be changed. This is a good example how a simulation result can help a design team in early development phase without any real testing and measurement.

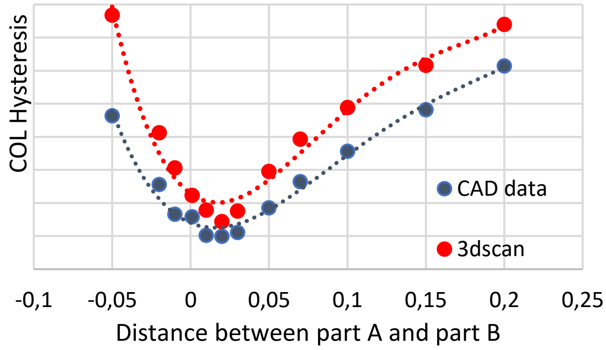


Figure 9 Comparison of simulation result based on geometry from CAD and real 3Dscan (the difference is influence of manufacturing process)

The graph in Figure 9 shows a comparison of simulation results with different 3D data. The blue line illustrates a result based on data from an early phase of development in CAD environment. To reduce the influence of the manufacturing process on the simulation result, manufactured parts were scanned and analyzed. The simulation result is shown in red. This was done later in the project phase and proved that it can significantly change the hysteresis result.

Therefore, in next projects it is planned to make collaboration with Moldflow simulations department. Moldflow can predict the manufacturing imperfections or dislocations and this data can be used as input for system model for hysteresis instead of using CAD data from design. This makes the simulation output more reliable concerning precision of both models, but also makes the result more realistic. Realizing this feature in early phase of the project is a key point to benefit from digitalization of testing process and will save a lot of time and money in next phases of each project.

5 Comparison with Measurements

All simulation models contributing into development process must be validated and verified. Otherwise, the project team cannot rely on simulation results or make simulation-based decision and must prove the simulation ideas with proper measuring test. In that case there is no significant cost reduction which is the biggest reason to do simulations at all. A once validated and verified model can be used in a lot of following projects it can save a lot of money with reducing numbers of physical testing, development of wrong design ideas, speeding up the troubleshooting process etc.

However, in our case verification of such a model is especially complex. System model of headlamp for hysteresis of adjusting processes deals with a lot of complex and hard to measure parameters such as friction, current position of components, very precise dimensions of the parts and forces. In the hysteresis test only, the final value is measured and even thought it fits to the simulation value, it is not certain that the model can identify the root cause properly.

Tables 1 and 2 show examples from projects. In Table 1 the simulated hysteresis in mm in x-direction is compared to a measurement and shows quite good agreement. Table 2 shows an analysis of the simulation results to identify the biggest contributor to the total hysteresis. In this case obviously Part C is the root cause of 70% of hysteresis in the whole system.

	Pr. X Simulation	Pr. X Measurments
Left HL average	11.85	11.12
Right HL average	8.01	8.1
Worst case	16.61	12.5
Best case	1.36	5.5

Table 1 Prediction of hysteresis value: Simulation vs measurements

	Simulations	Measurements
Part A	no	3 %
Part B	no	4 %
Part C	Root cause	70 %
Part D	no	5 %
Part E	no	6 %
Part F	Small influence	7 %
Part G	no	5 %

Table 2 Identifying the root cause in the system

6 Conclusion

In this paper a headlamp levelling system and its issues with hysteresis of the cut-off line between dark and light at the 10m wall is shown. A Modelica model based mostly on the Modelica standard library, using the CAD interface within the 3DExperience platform was described and proven as capable to be a great help in the development of a headlamp. The Simulation calculates and prints several internal parameters inside the adjusting system as torques and forces. Furthermore, the simulation model was improved with measured data of real parts through 3D scan. Verification methods were used to evaluate the precision of the simulation results. However, there are still some uncertain factors that were not considered in the model such as temperature of headlamp. In the future there is an ambition to upgrade the model to be even more valuable in the development process.

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