Modeling and Simulation of Steering Rack & Pinion Gears

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Introduction

The scope of the present work is the modeling and simulation of a Mechanical Steering Gear (MSG) functional test. Analytical model and multibody simulation result in good agreement with experimental test.

MSG Functional Test

The functional performances of a mechanical steering gear are assessed by specific tests [1].

Yoke Clearance is the relative movement of the rack yoke against the gear housing during the meshing due to gear manufacturing errors. The rack yoke displacement is recorded during the test by means of a linear transducer as a function of the rack axial position.

Rack Roll is the rotation of the rack bar around its axis during the meshing. The skew axis helical pinion and rack mesh generates a swing torque due to slidings in helix direction, tending to rotate the rack. The rack rotation is recorded by means of an angular transducer as a function of the rack axial position.

Gear CMM Inspection

The rack geometry is inspected by a Coordinate Measuring Machine (CMM). A parametric CAD model is generated to reproduce the real rack geometry with relevant errors.

References

[1] Pfeffer PE Harrer M. *Steering Handbook*. Springer, 1st edition, 2017.

[2] Piantoni A. et al. Marano D. Effects of gear manufacturing errors on stability of rack and pinion steering gear mesh. *WCCM Proceedings*, 2017.

[3] Kobayashi H. Shibata T. Estimaion of rack swing torque for rack and pinion steering gears. *JTEKT Engineering Journal*, No. 1006E, 2009.

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System Modeling

The aim of the proposed model is to replicate to replicate the real steering rack and pinion functional test. An analytical model to estimate yoke clearance variation is proposed in [2].

Multibody Model The kinematic model of the system is shown in Figure 1. A compliant contact force model is adopted and the normal contact force is calculated as a function of the penetration δ, of the master and slave patch as $f_n = K\delta^a + C\frac{\dot{\delta}}{|\dot{\delta}|}|\dot{\delta}|^b\delta^c$. The penalty stiffness K is calculated according to Hertz theory and the contact damping C is zero. Experimentally determined Stribeck friction curves are used in Rack/Pinion and Rack/Yoke contact modeling.

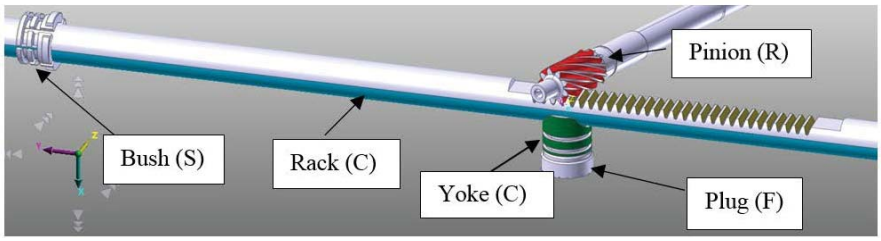

Figure 1: Mechanical Steering Gear Model; R: revolute joint, C: cylindrical joint, S: spherical joint, F: fixed joint

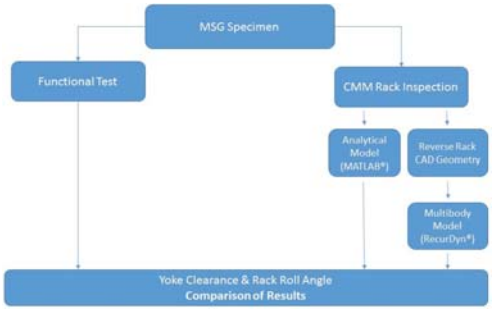

Figure 2: Flow chart of the study

Results

The CMM measurements of the case study rack are reported in Figure 3. A different trend of parameters related to left and right flanks is shown.

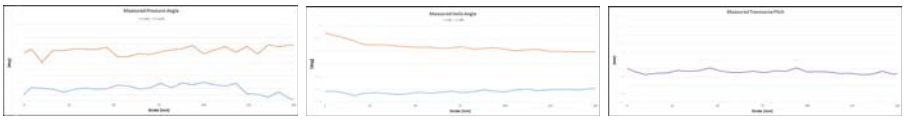

Figure 3: CMM Rack Measurements

Rack reverse geometry is generated according to CMM data and multibody simulation is perfomed. Figure 4 shows the comparison between analytical model, multibody model and experimental data.

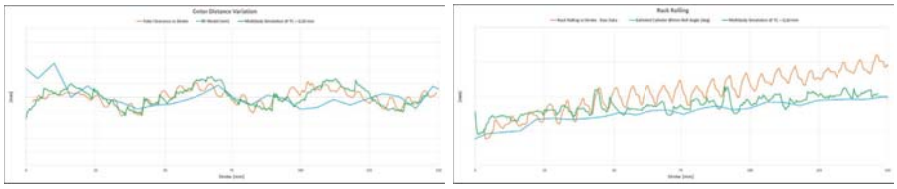

Figure 4: Yoke Clearance (1); Rack Rolling (2)

Results are in good agreement with experimental data. The developed technique allows a virtual validation of the performances of a Mechanical Steering Gear.