Bulletin of the *Transilvania* University of Braşov • Vol. 8 (57) No. 1 - 2015
Series I: Engineering Sciences

OPTIMAL KINEMATIC DESIGN OF A WINDSHIELD WIPER MECHANISM

Adrian C-tin BUTA[1]

Abstract: *In this paper we attempt to carry out the kinematic analysis and optimization of the windshield wiper mechanisms using the MBS (Multi-Body Systems) environment ADAMS of MSC Software. The kinematic model of the wiper mechanism contains the bodies, connected by geometric constraints (joints), and the kinematic restriction (motion driver) that control the angular position of the motor crank. The application is performed by considering a tandem pattern double-lever (with two blades) windshield wiper mechanism.*

Key words: *kinematics, multi-body system, optimization, wiper mechanism.*

1. Introduction

The increasingly growing demand for more comfortable vehicles imposes a new way for kinematic and dynamic analysis of the different subsystems, including the windshield wiper mechanism, by taking into consideration virtual models that are closer to the physical models on the vehicle. In this way, the complexity of the theoretical model is increasing, and for this reason such models cannot be analyzed with classical methods and programs.

In these terms, the usage of mechanical systems analysis and simulation environments is necessary. These programs automatically formulate and solve the kinematic and dynamic equations taking into consideration the geometric - elastic model of the system, and they allows important advantages: reduces time and cost, reduces the product cycles, reduces the number of expansive physical prototypes, allows making virtual measurements in any point and area of the system and for any parameter [1], [3-5].

In this paper, we attempt to analyze and optimize the kinematic model of the windshield wiper mechanisms using the multi-body systems (MBS) environment ADAMS of MSC Software. The modelling of the wiper mechanism as multi-body system is made in the following steps [2], [6]: modeling bodies and restrictions, establishing the coordinate systems attached to bodies, defining the part's geometry in the local coordinate frames, defining the orientation of the bodies and determining the transformation matrix from the local frame to the global reference frame, defining the geometric and kinematical constraint equations. Parameterizing the virtual model, defining the design variables, defining the objective function for optimization and performing design study makes the kinematic optimization of the wiper mechanisms.

2. Kinematic Model of the Wiper System

The windshield wiper mechanisms are vehicle-specific systems in which the

[1] Schaeffler Romania.

wiping motion is transferred from the wiper motor to the pivot-shaft assemblies via linkages. A compact wiper system consists of the following components: wiper motor with thermo-switch, wiper gearing, motor crank, steel base-plate, crank linkage, pivot-shaft assembly with oscillating crank, and second pivot-shaft assembly with plate (for parallel wipe pattern), respectively. The linkage forces are supported by the sheet metal of the car body.

For the present-day vehicles, the following wiper systems are frequently used [10]: single-lever systems with parallel wipe patterns, single-lever systems with sector wipe patterns, opposed-pattern double-lever systems with parallel wipe patterns, opposed-pattern double-lever systems with overlapping sector wipe patterns, tandem-pattern double-lever systems with overlapping sector wipe patterns, and tandem-pattern three-lever systems with extra-wide overlapping sector wipe patterns, respectively.

The kinematic model of the windshield wiper system contains the rigid parts (bodies) from the wiper mechanism, connected through geometric constraints (standard joints), and the geometric parameters that define the mechanism (the locations of the joints); the input is made using a kinematic restriction (motion generator - driver), applied in the joint between the motor crank and the body's base-plate (rigidly connected to ground), which controls the angular position or velocity of the motor crank.

For this paper, a tandem pattern double lever wiper system was considered (Figure 1). The wiper mechanism contains two spatial four-bar linkages: ABCD - to command the left wiper arm/blade, and DC_1EF - to command the right wiper arm/blade.

The motor crank (1) and the left / right wiper arms (3, 5) are connected to the grounded part (i.e. the car body) using revolute joints (A, D, and F). The crank linkages (2, 4) are connected to the motor crank, respectively to the wiper arms, using spherical (B, E) and cylindrical joints (C, C1).

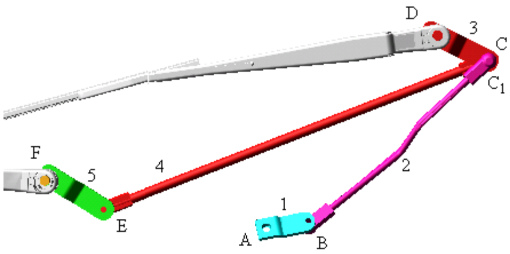


Fig. 1. *The tandem pattern double lever wiper mechanism*

The geometric model of the windshield wiper mechanism was made using CAD software (CATIA), and then the geometry was transferred to ADAMS using the STEP (Standard for the Exchange of Product Model Data) file format.

3. Kinematic Analysis in MBS Environment

In a multi-body systems environment, such as ADAMS, the steps to create a virtual (software) model mirror the same steps to build a physical (hardware) model, as follows: build - create parts, constrain the parts (using geometric and kinematic restrictions), and test - measure characteristics, perform simulations, review animations, review numeric results as plots.

The degree of mobility (DOM) of the wiper mechanism is given by the Grubler count, $DOM = 6n - \Sigma r_g = 30 - 29 = 1$, where: n - the number of mobile bodies, and Σr_g - the total number of geometric constraints ($r_g = 5$ - revolute joint, $r_g = 4$ - cylindrical joint, $r_g = 3$ - spherical joint). In the kinematic model, this degree of mobility is controlled by a motion generator of type $\varphi_1(t)$. Considering the input speed of the motor crank n_1 = 65 [rot/min], we obtain: $\omega_1 = \pi n_1 / 30 = 6.803$, so that $\varphi_1 = \omega_1 t = 6.803\ t$ [rad/sec].

The kinematic analysis of the windshield wiper mechanism is made having in view to determine the specific parameters that define the behaviour of the system [7-9]: parking position (the wiper arm's rest position on the windshield), wiping angle, and wipe-pattern size. The input data for analysis consist from the windshield dimension (size), the installation point for drive unit, and the clamping length (maximum thickness of the sheet steel to which the pivot-shaft assembly is fastened).

Analyzing the kinematic model of the above-described wiper mechanism, a lot of results were obtained. For example, in Figure 2 the wiping angles and the angular velocities for the left and right wiper arms are shown. At the same time, Figure 3 shows several graphical simulation frames, which were obtained by using the ADAMS/Animation module.

4. Optimal Kinematic Design

The kinematic optimization of the windshield wiper mechanism is made with the following steps: parameterizing the model, defining the design variables, defining the design objective for optimization, performing design study, and optimizing the model on the basis of the main design variables.

The parameterization of the wiper mechanism is made by the points that define the structural model, in fact the locations of the geometric constraints - joints (see Figure 1). The parameterization simplifies changes to model because it helps to automatically resize, relocate and orient parts. In this way, relationships into the model are created, so that when a point is changed, any other objects (bodies, joints) that depend on it will be updated.

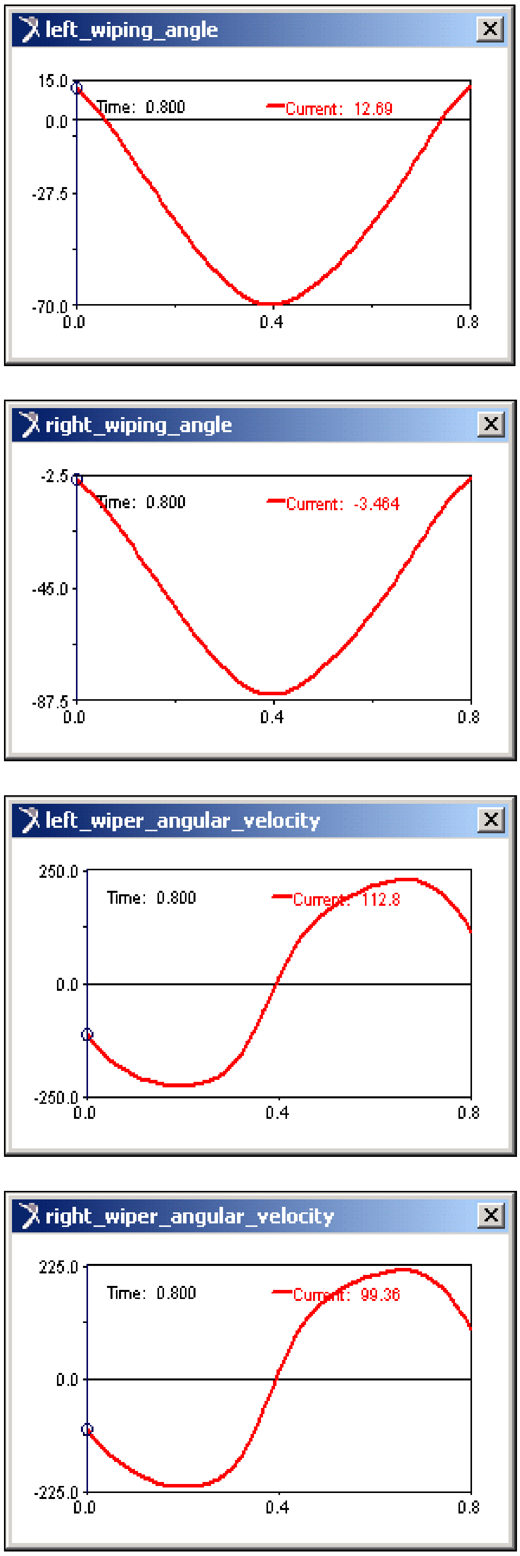


Fig. 2. *Results of the kinematic analysis*

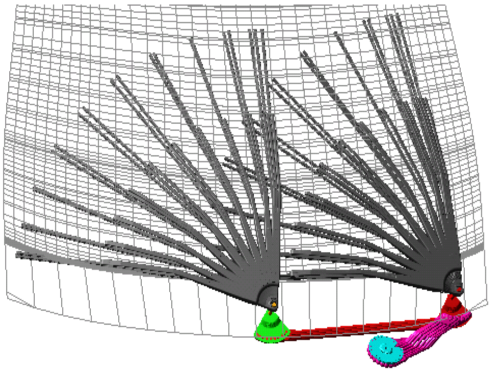
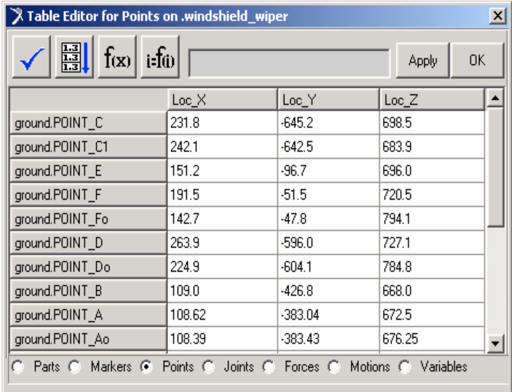


Fig. 3. *Graphical simulation frames*

Design variables represent elements in model that allow creating independent parameters and tie modeling objects to them. In our case, the design variables represent the locations for the design points. Design variable allows running automated simulations that vary the values of the variable over specified ranges to understand the sensitivity to the variable or to find the optimum values.

In addition, using design variables, design studies can be performed. Design study represents a set of simulations that help to adjust a parameter to measure its effect on the performance of the wiper system model. Design study describes the ability to select a design variable, sweep the variable through a range of values and then simulate the motion behaviour of the various designs in order to understand the sensitivity of the overall system to these design variations. As result, design study allows to identify the main design variables, with great influence on the kinematic behaviour of the wiper system.

Therefore, for beginning, the points that define the structural model of the windshield wiper system, shown in the table editor from Figure 4, were modeled in the global coordinate frame, which is an inertial frame attached to car body (the points A_0, D_0, and F_0 were used to define the axis of the revolute joints). Afterwards, the geometry of the bodies and the locations of the joints were attached to the design points. In these conditions, when a coordinate of a point will be modified, the objects that depend on it (bodies, joints) will be accordingly changed.



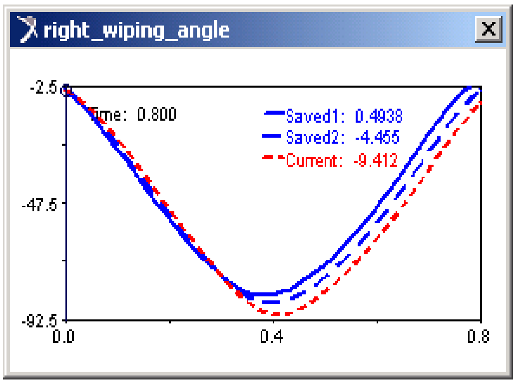
	Loc_X	Loc_Y	Loc_Z
ground.POINT_C	231.8	-645.2	698.5
ground.POINT_C1	242.1	-642.5	683.9
ground.POINT_E	151.2	-96.7	696.0
ground.POINT_F	191.5	-51.5	720.5
ground.POINT_Fo	142.7	-47.8	794.1
ground.POINT_D	263.9	-596.0	727.1
ground.POINT_Do	224.9	-604.1	784.8
ground.POINT_B	109.0	-426.8	668.0
ground.POINT_A	108.62	-383.04	672.5
ground.POINT_Ao	108.39	-383.43	676.25

Fig. 4. *Table editor for design points*

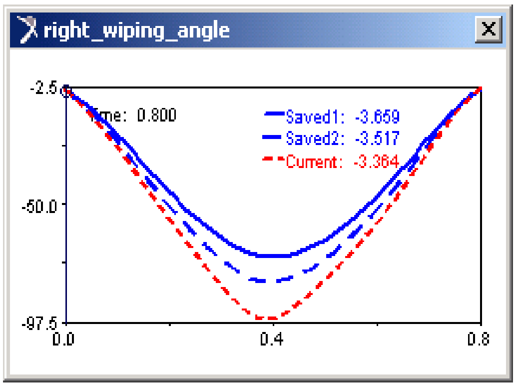
In the next step, the global coordinates of the points were transformed in design variables, having in view to control the virtual model in the optimization process. Each coordinate is a design variable, therefore for the above-described spatial windshield wiper mechanism, 30 design variables will result, as follows: DV_1 → X_A, DV_2 → Y_A, DV_3 → Z_A, DV_4 → X_{A0}, DV_5 → Y_{A0}, DV_6 → Z_{A0}, and so on.

In this way, ADAMS creates a variable with the initial value, and modifies the point to use the design variable as the coordinate value. The initial value and the variation field (range) for each design variable can be established in order to keep the wiper system in rational constructive limits.

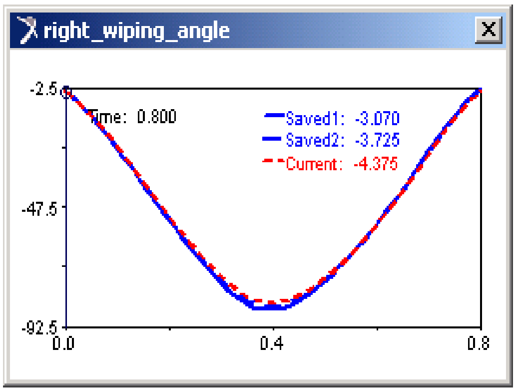
The design objectives are represented by the parameters that describe the kinematic behavior of the system (see section 3). In this paper, the wiping angles were considered as goal for optimization. For beginning, measures that define the left and right wiping angles were modeled using the orientation by Euler angles, and then the design objectives were attached to these measures. In order to increase the wiping angles, the maximum absolute values during simulation were taken into consideration.



a)



b)



c)

Fig. 5. *Results of the design studies for the right wiping angle*

Having in view to identify the influence of the design variables on the design objectives, design studies were successively performed for each design variable, in their variation fields (ranges). In this way, two types of design variables are obtained: main variables, which have great influence on the design objectives, and secondary variables (their influence can be neglected).

As example, the influence of the coordinates of the point B on the right wiping angle is shown in Figure 5, considering the following variation fields: a) X_B ={105, 110, 115}, b) Y_B = {–420, –425, –430}, c) Z_B = {665, 670, 675}. According to these diagrams, Y_B and X_B are main design variables, while Z_B is a secondary variable.

Analyzing such comparative results, all the main design variables can be identified. These variables are taken into consideration for the kinematic optimization of the windshield wiper mechanism.

Afterwards, the inverse dynamic model, which includes the forces that act in the wiper system, can be used to determine the turning moment applied to the motor crank in order to generates the kinematic behavior. Finally, the dynamic model is used to evaluate the real behavior of the wiper mechanism. These aspects will be approached in a future work (paper).

5. Final Remarks

The study presented in this paper demonstrates the capabilities of the modelling & simulation in virtual environment in the design process of the windshield wiper mechanisms. Simulation-based design practices allow to more quickly assessing form, fit, and function of the wiper systems.

In this way, there is created the frame to optimize the kinematic & dynamic behaviour of the windshield wiper mechanisms in a fraction of the cost of traditional hardware prototype processes.

References

1. Alexandru, C.: *Kinematic and Dynamic Analysis of the Windshield Wiper Mechanisms Used for Motor Vehicles*. In: Bulletin of the *Transilvania* University of Braşov (2004) Vol. 11 (46), Series A, p. 7-12.
2. Alexandru, C.: *Design Algorithm of the Windshield Wiper Mechanisms of the Passenger Vehicles*. In: Proceedings of the 10th International Research Expert Conference Trends in the Development of Machinery and Associated Technology - TMT, Barcelona-Lloret de Mar, 2006, p. 757-760.
3. Alexandru, C.: *Software Platform for Analyzing and Optimizing the Mechanical Systems*. In: Proceedings of the 10th IFToMM International Symposium on Science of Mechanisms and Machines - SYROM, Braşov, 2009, p. 665-677.
4. Alexandru, C.: *A Mechatronic Approach of the Windshield Wiper Mechanisms*. In: Annals of the Oradea University, Fascicle of Management and Technological Engineering (2012) Vol. XI, No. 1, p. 3.1-3.6.
5. Alexandru, C., Barbu, I.: *Functional Design of the Windshield Wiper Mechanisms Using Virtual Models*. In: Proceedings of the IX IFToMM International Conference on the Theory of Machines and Mechanisms, Liberec, 2004 p. 23-28.
6. Alexandru, C., Barbu, I.: *Modeling of the Windshield Wiper Mechanisms as Multibody Systems*. In: Proceedings of the IX IFToMM International Conference on the Theory of Machines and Mechanisms, Liberec, 2004, p. 29-34.
7. Buta, A.C.: *Study on the Friction between the Wiper Blade and the Windshield*. Bulletin of the *Transilvania* University of Braşov (2014) Vol. 7 (56), No. 1, Series I, p. 1-6.
8. Buta, A.C.: *The Conceptual Design of a Windshield Wiper Mechanism*. In: Annals of the Oradea University, Fascicle of Management and Technological Engineering (2007) Vol. VI, p. 120.
9. Buta, A.C.: *The Conception of a New Action System of the Windshield Wipers Mechanisms and the Reciprocal Validations of the Physical and the Virtual Results*. In: Annals of the Oradea University, Fascicle of Management and Technological Engineering (2007) Vol. VI, p. 121.
10. *** *Wiper Systems for Commercial Vehicles*. Bosch GmbH, 1997.