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A MECHATRONIC APPROACH OF THE WINDSHIELD WIPER MECHANISMS

Alexandru Cătălin
"Transilvania" University of Braşov
calex@unitbv.ro

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Abstract: In this paper we attempt to present some aspects regarding the modeling and simulation of the windshield wiper mechanisms of the commercial vehicles, using the multi-body systems software MSC.ADAMS, as well as the control of these complex mechanical systems. The objective is to determine the control torque applied to the motor crank in order to generates the cinematically prescribed behavior. The control system, developed with ADAMS/Controls and MSC.EASY5, is based on the error between the actual wiper arm position and the imposed position. As example, a single lever wiper system, containing a spatial four-bar linkage, is taken into consideration. The geometric model of the windshield wiper mechanism is made using CAD software (CATIA), the geometry being transferred to ADAMS by using the STEP file format. The virtual model includes the friction forces between the lamella and windshield, the direction of the force depending on the sign of wiper arm velocity.

1. INTRODUCTION

Important publications reveal a growing interest in analysis methods for multi-body systems (MBS) that may facilitate the self-formulating algorithms, having as main goal the reducing of the processing time in order to make possible real time simulation [1-3]. These methods were used to develop powerful modeling and simulation programs that allow building and simulating a virtual (software) model of any mechanical system (mechanism). In the MBS theory, the mechanism is considered as a constrained, multi-body, spatial mechanical system, in which body elements are connected through mechanical joints (revolute, translational, spherical joint etc.) and force elements (springs, dampers, actuators).

On the basis of advanced design prototyping software, designers have the possibility to build models of not just parts but entire mechanical systems, and then to simulate their behavior and optimize the design before building an expensive physical prototype. No longer is it necessary to wait months to build a hardware prototype, instrument it, run tests on it, and make a small number of expensive modifications to it in order to assess proposed design changes. This technology, called Functional Virtual Prototyping (FVP), it is a software-based engineering process, which enables modeling mechanical system, simulating its motion under real operating conditions and, finally, optimizing the form, fit, function, and manufacturing characteristics in a fraction of the cost of traditional hardware (physical) prototyping processes [4-6].

Virtual prototyping has important implementations in the automotive industry. Every major auto manufacturer, as well as leading tire manufacturers and auto racing teams, uses digital mock-up and functional virtual prototyping techniques to refine and prove out their suspension design, vehicle dynamics, engine design, power-train engineering, body hardware engineering, NVH (noise, vibration, and harshness) and ride, tire - roadway interaction, driver behavior, controls design, safety systems, vehicle durability. Regarding the body hardware engineering, functional virtual prototyping is frequently used in door, trunk, and hood latch design, trunk and hood hinge linkage design, seat mechanism design, window mechanism design, windshield wiper simulation and refinement and so on.

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

In the present paper, we attempt to analyze and control a windshield wiper mechanism, having in view to evaluate the dynamic behavior. The analysis is made using the MBS software ADAMS (Automatic Dynamic Analysis of Mechanical Systems). The control system, developed with ADAMS/Controls and EASY5 (Engineering Analysis System), is used to obtain the crank turning moment, which is the input parameter in the dynamic analysis.

2. ANALYZING & SIMULATING THE VIRTUAL MODEL

For the present-day vehicles, the following windshield wiper systems are frequently used: single-lever systems with sector wipe patterns, single-lever systems with parallel wipe patterns, opposed-pattern double-lever systems with overlapping sector wipe patterns, opposed-pattern double-lever systems with parallel 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.

The analysis of the windshield wiper system is made having in view to determine the specific parameters that define the system’s behavior, as follows: parking position, wiping angle, and wipe-pattern size. Generally, to analyze the windshield wiper mechanisms, three mechanical models are used [7]:

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

b. inverse dynamic model - includes the kinematic model and, in addition, the external & internal loading (the friction forces between the wiper blade and windshield, and the mass characteristics); this model is used to determine the turning moment applied to the motor crank in order to generates the kinematic behavior;

c. dynamic model - includes the inverse dynamic model, but the input is made through the above-determined torque; the aim is to evaluate the “real” behavior of the windshield wiper system.

In ADAMS, the steps to create a virtual (software) model of the windshield wiper mechanisms mirror the same steps to build a physical (hardware) prototype, as follows [8]: build - create parts, constrain the parts (using geometric restrictions), create forces and torques acting on the parts; test - measure characteristics, perform simulations, review animations, review numeric results as plots; validate - import test data, superimpose test data on plots; refine - add friction, define flexible bodies, define controls and others.

As instant, in this paper, a single-lever wiper system was considered, which includes a four-bar spatial linkage (fig. 1). The motor crank and the wiper arm are connected to ground (i.e. the car body) using revolute joints. The crank linkage is connected to the motor crank and to the wiper arm by spherical joints. The mechanism has one degree of mobility, namely the rotation of the motor crank. The solid model of the wiper mechanism was made using CAD software (CATIA). The geometry was transferred to ADAMS/View using the STEP file format.

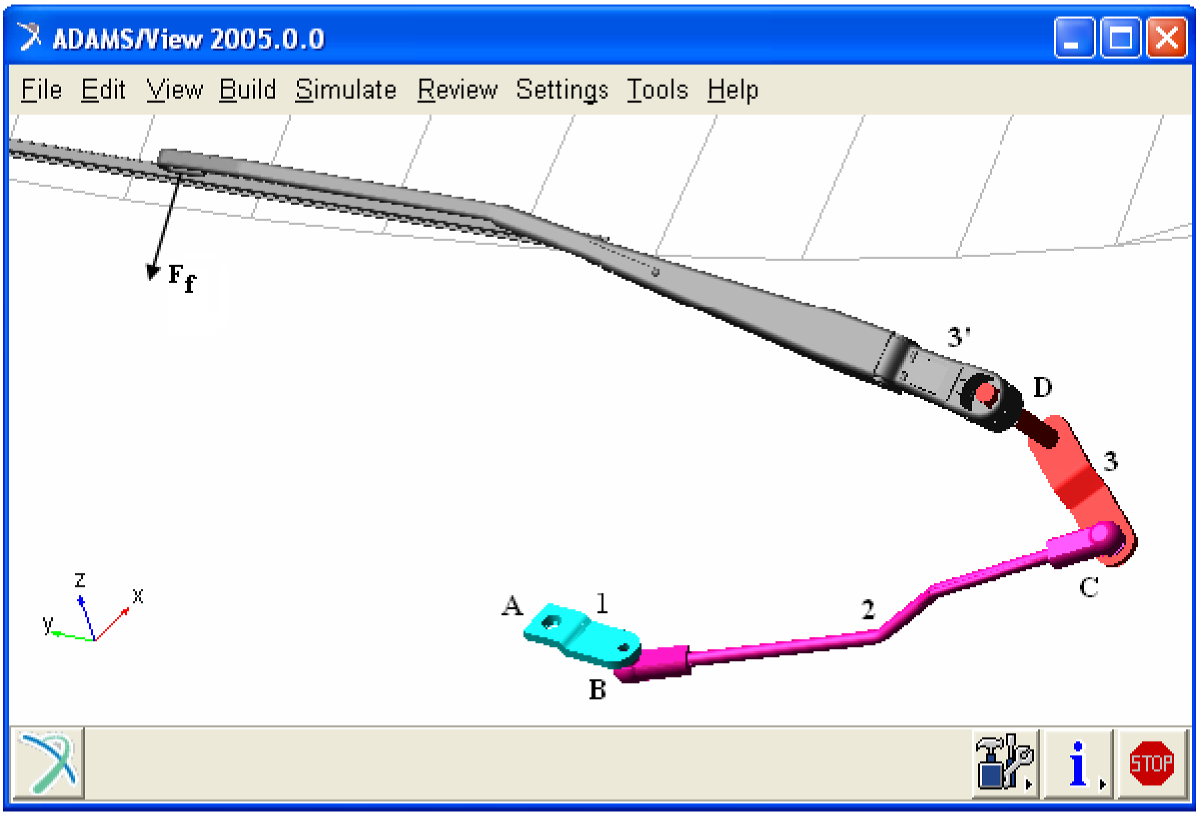

Figure 1. The virtual model of a single-lever windshield wiper mechanism (MSC.ADAMS)

In the kinematic & inverse dynamic models, the degree of mobility is kinematically controlled by using a motion generator, $\varphi_1(t)$. Considering the input speed for the motor crank n_1=65 rot/min, will results: $\omega_1 = \pi \cdot n_1 /30 = 6.803$ rad/sec $\rightarrow \varphi_1 = \omega_1 \cdot t = 6.803 \cdot t$. For the dynamic model, the kinematic constraint is replaced with the torque applied on the motor crank; therefore, the dynamic model has one independent generalized coordinate.

Analyzing the virtual model of the above-described windshield wiper mechanism, considering as input the motion generator applied in the revolute joint of the motor crank to car body, the kinematic parameters were obtained, for example the wiping angle and the angular velocity of the wiper arm (fig. 2). On the other hand, the graphic simulation offers a global image regarding the windshield wiper behavior (fig. 3).

The friction force that acts on the wiper lamella depends on the friction coefficient between rubber blade and windshield, and the normal force generated by the spring mounted between wiper arm and oscillating crank. Considering the dry wiping regime, the friction force, which is applied in the connection point between wiper arm and lamella (see fig. 1), will be F_f = 8.7 N.

To model the friction force, in ADAMS/View interface, the “Function Builder”, which is a versatile tool that allows creating / modifying functions and parameterizing values for various entities, was used. The direction of the friction force depends on the sign of wiper arm’s velocity. The SIGN function transfers the sign of one expression representing a numerical value to the magnitude of another expression representing a numerical value, as follows: SIGN(a1, a2) = ABS(a1) if a2≥0, SIGN(a1, a2) = -ABS(a1) if a2<0. In our case, “a1” represents the friction force magnitude (F_f = 8.7 N), and “a2” is the angular velocity of the wiper arm, obtaining (fig. 4): SIGN(8.7,angular_velocity).

Afterwards, it is necessary to determine the turning moment to the motor crank, which replaces the motion generator in order to generate the kinematically prescribed behavior.

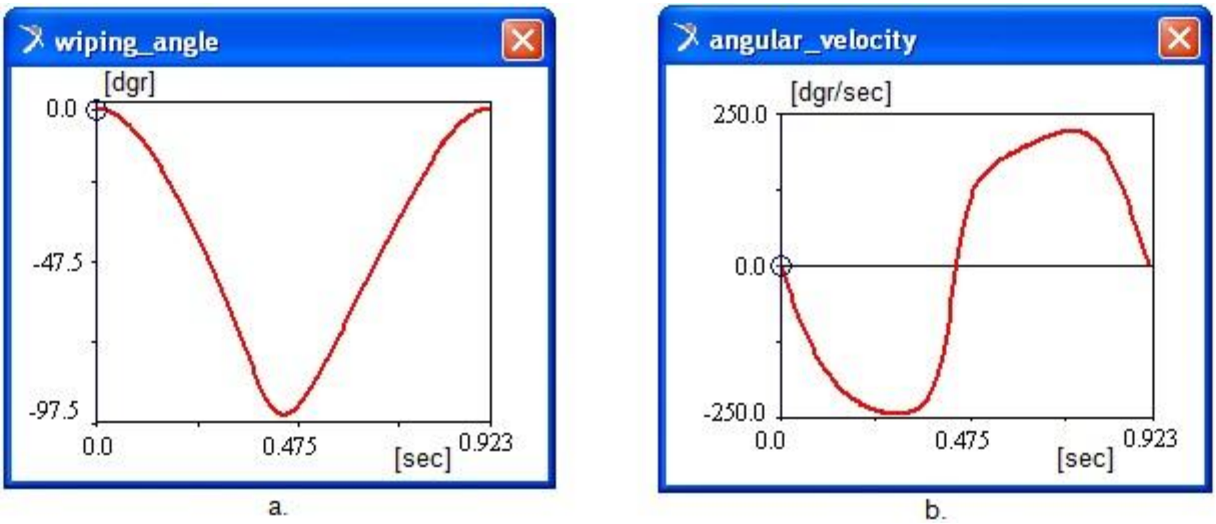

Figure 2. Time-history variations of the interest kinematic parameters

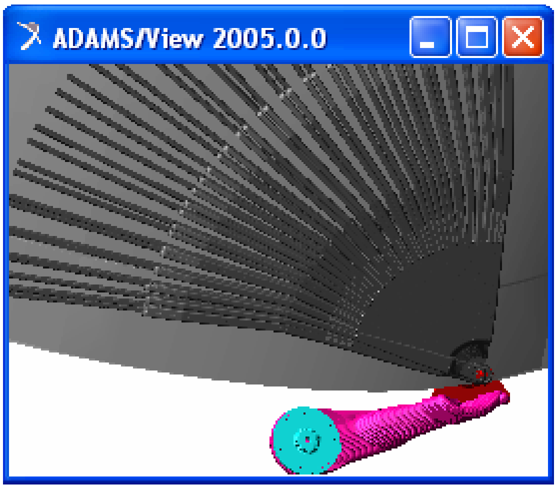

Figure 3. Graphic simulation frames

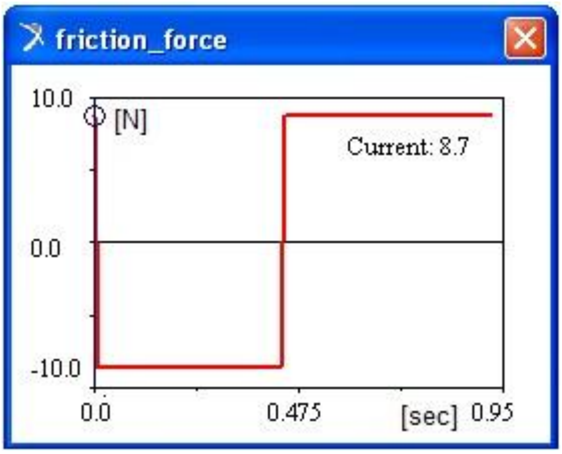

Figure 4. Time-history variation of the friction force

3. CONTROLLING THE WINDSHIELD WIPER SYSTEM

The torque that rotates the motor crank will be computed by a control system based on the error between the actual and imposed wiper lamella position. ADAMS/Control is a plug-in to ADAMS/View that allows integrating motion simulation and controlling system design in the virtual model. The four-step process of combining controls with a mechanical system involves: build the model - the first step in working with ADAMS/Controls is to build an ADAMS model, which includes all necessary geometry, constraints, forces; identify the ADAMS inputs and outputs - the outputs describe the variables that go to the controls application, and the inputs describe the variables that come back into ADAMS; build the block diagram - build the control system block diagram with a control software, and include the ADAMS plant in the block diagram; simulate the mechatronic model (mechanical & control).

The input in the windshield wiper model is the control torque, applied to the motor crank (crank turning moment). The output, which will be transmitted to the controller, is the wiping angle. ADAMS/Controls and control application communicate by passing state variables back and forth. Therefore, it is necessary to define the input & output variables and the functions that those reference, with a set of ADAMS state variables.

For the input state variable, representing the motor torque, the run-time function is 0.0 during each step of the simulation, because the motor torque will get its value from the control application. In this way, the run-time function for the input variable is: VARVAL(motor_torque), where VARVAL (variable value) is an ADAMS function that returns the value of the given variable. In other words, the input control torque (crank_turning_moment) gets its value from the input variable (fig. 5).

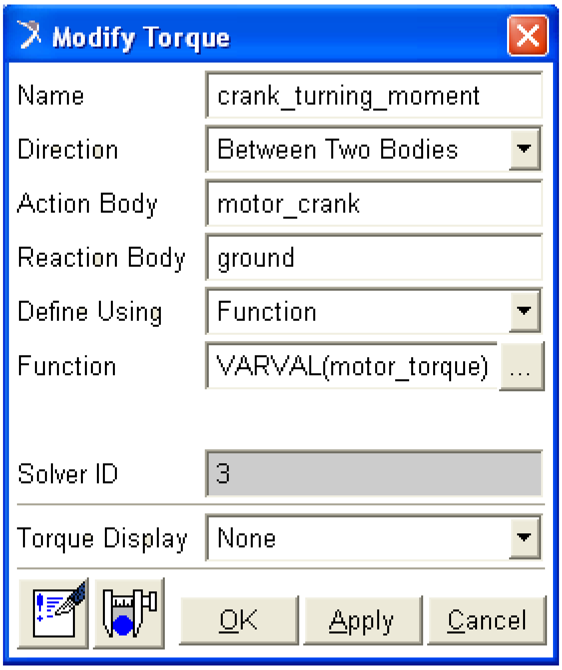

Figure 5. Modeling the input control torque

For the output state variable, representing the wiping angle, the run-time function returns the angle about the z-axis (the vertical axis about which the lamella rotates). The mathematic expression of the function is: AZ(To Marker, From Marker), where the markers represent coordinates systems that belong to the adjacent parts, placed in the revolute joint of the wiper arm to car body. Thus, the function assigns the rotational position of the lamella to the output state variable (fig. 6).

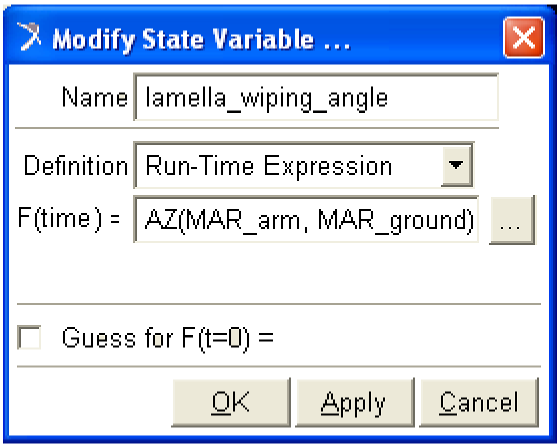

Figure 6. Modeling the output state variable

The next step is for exporting the ADAMS plant files for the control application. The plant input refers the input state variable (motor_torque), while the plant output refers the output state variable (lamella_wiping_angle). ADAMS/Controls saves the input & output information in a specific file (".m" - for MATLAB, ".inf" - for EASY5). It also generates a command file (.cmd) and a dataset file (.adm) which will be used during the simulation. With these files, the control system block will be created by using a DFC (Design for Control) application.

For this paper, the DFC software solution MSC.EASY5 was used to create the control system of the windshield wiper mechanism. The control block diagram (fig. 7) contains the ADAMS Mechanism interface block, which is used to select the exported ADAMS model (the ".inf" file), and to configure the execution mode, in this case Function Evaluation - no feedthrough. This execution mode is used when the ADAMS plant outputs are not instantaneously affected by the ADAMS plant inputs, which is the case when the plant outputs are positions and velocities, and the plant inputs are forces and torques (in our case, the plant output is position - the wiping angle, while the plant input is torque - the motor torque). In addition, the control system model contains the following blocks: Tabular Function - to define the imposed values of the wiping angle as a function of time (the reference signal, $\varphi_1=6.803\cdot t$ - see section 2), Summing Junction - to subtract the current wiping angle from the imposed angle, Gain Block - to amplify the error signal. The output from the amplification block, which acts as a controller, is the motor torque. The controller synthesis was performed in an optimization process, considering the amplification factor (K) as a design variable, the design objective being the minimization of the error; this study will be explained in detail in another paper.

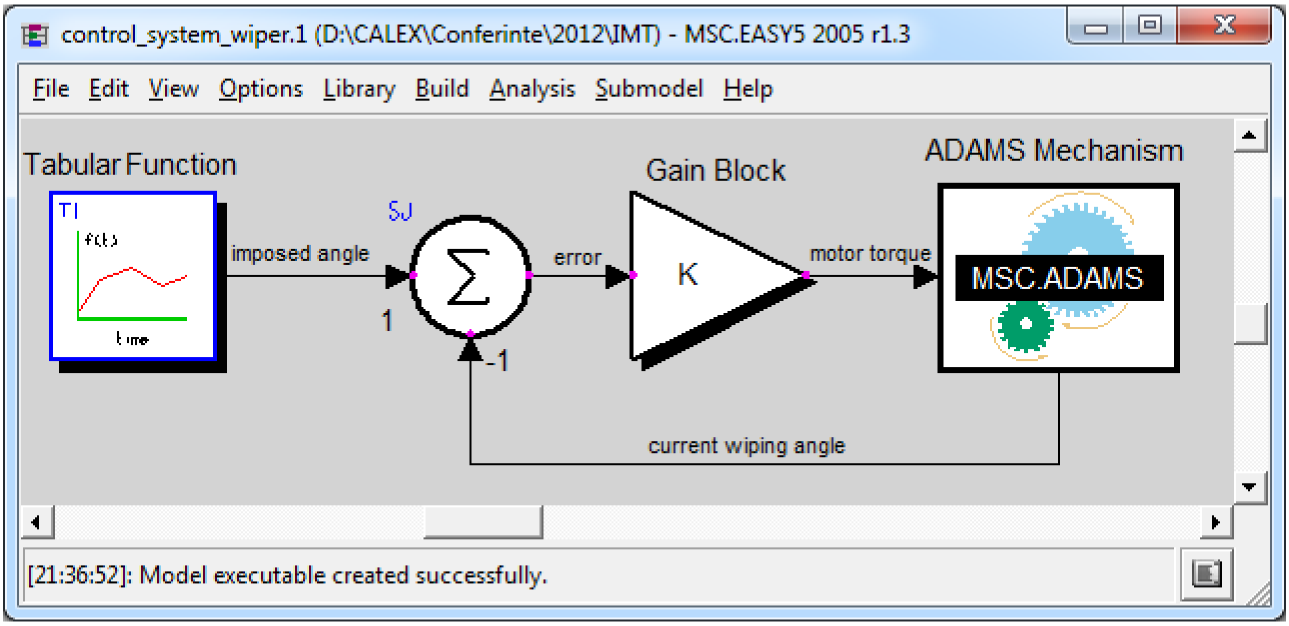

Figure 7. The control system block diagram (MSC.EASY5)

4. RESULTS & CONCLUSIONS

In the mechatronic model, ADAMS accepts the motor torque from EASY5 and integrates the mechanical model in response to this. At the same time, ADAMS provides the current wiping angle for EASY5 to integrate the control system model. In this way, the time-history of the motor torque is obtained (fig. 8), for a complete rotation of the motor crank; this can be used as input for the dynamic analysis of the windshield wiper mechanism.

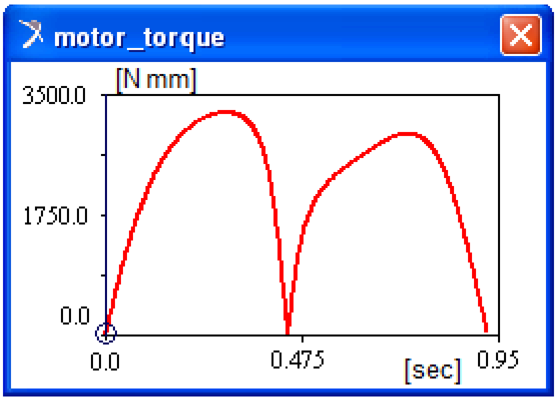

Figure 8. Time-history variation of the motor torque

The application is a relevant example regarding the mechatronic approach in the design & simulation process of the windshield wiper mechanisms, achieving more realistic results. The future researches will be focused on the modal analysis of the wiper system. Integrating flexibilities into model allows to capture inertial and compliance effects during simulations, to study deformations of the flexible components, and to predict loads with greater accuracy.

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