KINEMATIC AND DYNAMIC ANALYSIS OF THE WINDSHIELD WIPER MECHANISMS USED FOR MOTOR VEHICLES

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Abstract: *In this paper we attempt to analyze and simulate the windshield wiper mechanisms, using the multibody systems software ADAMS. The design algorithm involves three mechanical models: kinematic model – to performe the positional analysis of the wiper system, inverse dynamic model – to determine the torque applied to the motor crank in order to generate the kinematically-prescribed behavior, and dynamic model – to evaluate the "real" behavior of the wiper system.*

Key words: *windshield wiper, multibody system, kinematics, dynamics.*

1. Introduction

Recent publications reveal a growing interest in the analysis of methods for multibody systems that may facilitate the self-formulating algorithms, having as main goal the reducing of the processing time in order to make real time simulation possible [1, 2, 3]. These methods were used to develop powerful modelling and simulation programs (MBS - MultiBody Systems) that allow building and simulating a virtual (software) model of any mechanical system.

In the MBS theory, the mechanism is considered a constrained, multibody, spatial mechanical system, in which body elements are connected through mechanical joints (revolute, translational, spherical joint etc.) and force elements (springs, dampers, actuators etc.).

The main difference between the mechanical system dynamics and the conventional structural system dynamics is the presence of a high degree of geometric nonlinearity associated with large rotational kinematics. Governing equations for conventional structural dynamics are linear differential equations, while those equations for mechanical system dynamics are nonlinear differential equations that are coupled with nonlinear algebraic equations of kinematic constraints.

In these terms, in the present paper, we attempt to carry out the kinematic and dynamic analysis of the windshield wiper mechanisms used for motor vehicles, considering the mechanisms modeled as multibody systems.

The analysis and simulation are made by means of MBS software ADAMS (Automatic Dynamic Analysis of Mechanical Systems) – MSC / Mechanical Dynamics Incorporated, which is licensed to Product Design and Robotics Department from „Transilvania" University of Braşov (CASMA Laboratory).

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2. Virtual prototyping phases & applications

In ADAMS, the steps to create a virtual (software) model mirror the same steps to build a physical (hardware) prototype, as follows:

- 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, implement force functions, define controls;
- optimize - parameterize, define design variables, perform manual studies, perform design sensitivity studies, perform design of experiments, perform optimization studies.

On the basis of advanced design prototyping software, such as ADAMS, 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), is a software process that enables modelling 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 prototype processes.

In addition to FVP, which investigates product function and operating performance, Digital Mock-Up (DMU) is to quickly assess form and fit of entire assemblies of three-dimensional solid models comprising a product, respectively Virtual Factory Simulation (VFS) - to assess manufacturability and assembly of the product. Enterprise-wide, Product Data Management (PDM) is the “glue” that enables these system-focused solutions to be successful by making all of the up-to-date component data readily available and manageable.

Virtual prototyping has become very important 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 platform to refine and prove out their suspension design, vehicle dynamics, engine design, powertrain 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, windshield wiper simulation and refinement, seat mechanism design, window mechanism design.

Among these applications, the functional design of the windshield wiper system will be at length described in the following chapters of the paper.

3. Design algorithm of the windshield wiper mechanisms

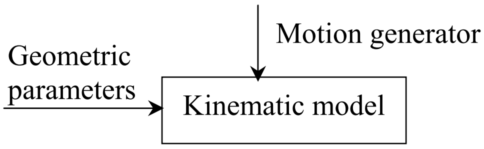
For the present-day motor vehicles, the following types of wiper systems are frequently used [4]: single-lever systems with sector wipe patterns, single-lever systems with parallel wipe patterns, opposed-pattern double-lever systems with overlapping sector wipe patterns, opposed-pattern double-lever 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. These are vehicle-specific systems in which the wiping motion is transferred from the wiper motor to the pivot-shaft assemblies via linkage mechanisms.

A compact wiper system consists of the following components: wiper motor with thermo-switch, wiper gearing, motor crank, steel baseplate, crank linkage, pivot-shaft assembly with oscillating crank, and second pivot-shaft assembly with plate (for parallel wipe pattern), respectively.

The analysis of the wiper system is made so as to determine the specific parameters that define the system's behavior: parking position (the wiper arm's rest position on the windshield), wiping angle, and wipe-pattern size. The input data consist of: windshield size, installation point for drive unit, and clamping length (maximum thickness of the sheet steel to which the pivot-shaft assembly is fastened).

In these terms, in order to analyze the windshield wiper mechanisms, three mechanical models have been developed (see fig. 1):

a. *kinematic model* – which 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 motor crank and body's baseplate (rigidly connected to ground), which controls the angular position / velocity of the motor crank;



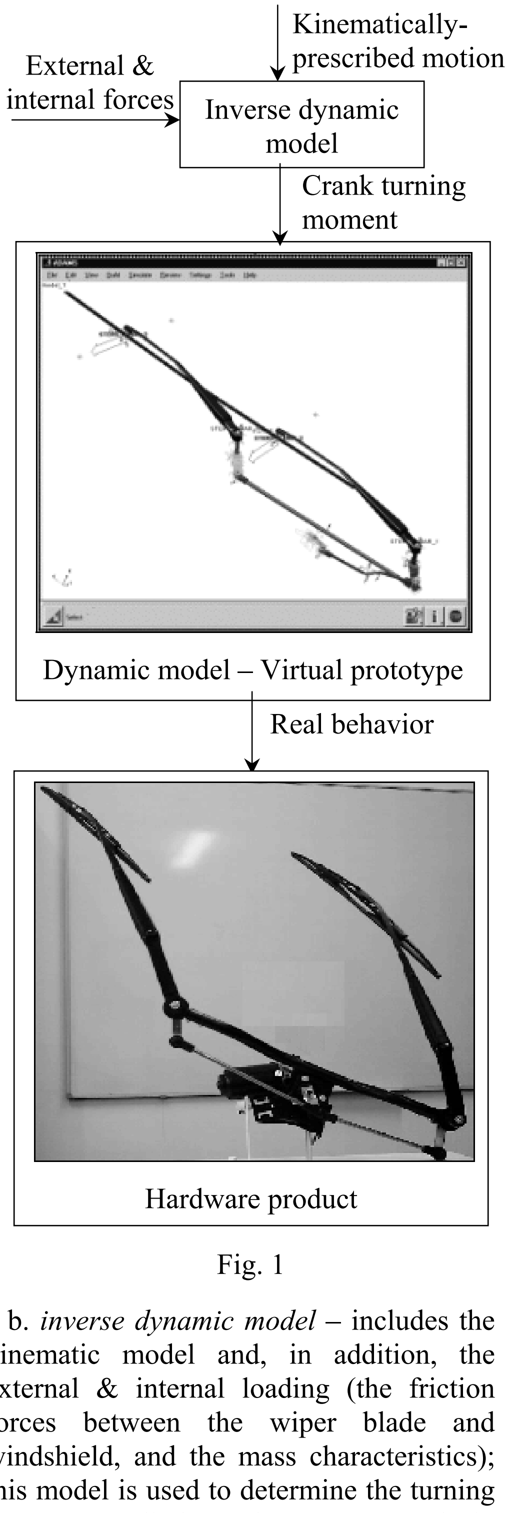


Fig. 1

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 generate the above-determined motion (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 wiper system (virtual prototype).

As an example, in this paper, a tandem pattern double-lever wiper system (corresponding to a domestic passenger car - DACIA Nova type) was considered. The wiper mechanism contains two four-bar spatial linkages (fig. 2): ABCF – command mechanism, from the wiper motor crank to the left wiper arm, and FC_1DE – connection mechanism, which transmits the revolute motion to the right wiper arm.

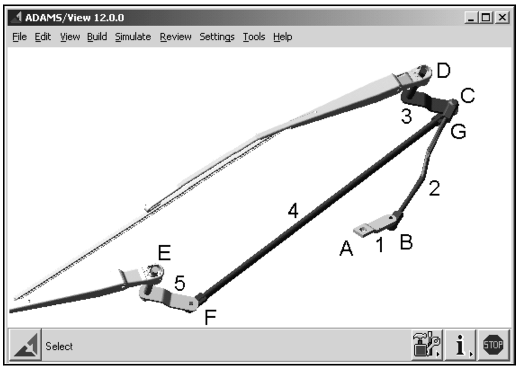


Fig. 2

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

The solid model of the wiper mechanism was made using CAD software (CATIA). The geometry was transferred to ADAMS using the STEP (Standard for the Exchange of Product Model Data) format.

The wiper blade was modelled with FEA software (NASTRAN), the transfer to ADAMS being made by the MNF (Modal Neutral File) file format.

The degree of mobility of the wiper system is given by the Grubler count,

$DOM = 6 \cdot n - \Sigma r_g = 30 - 29 = 1$,

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 & inverse dynamic models, this degree of mobility is kinematically controlled, using the motion generator $\varphi_1(t)$. Considering the input speed for the motor crank n_1=65 [rot/min], will results: $\omega_1 = \pi n_1 / 30 = 6.803 \rightarrow \varphi_1 = \omega_1 t = 6.803\ t$ [rad/sec]. 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 (the position angle of the motor crank, φ_1).

The friction force that acts on the wiper blade (fig. 3) 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 blade, will be $F_f = 8.7$ N.

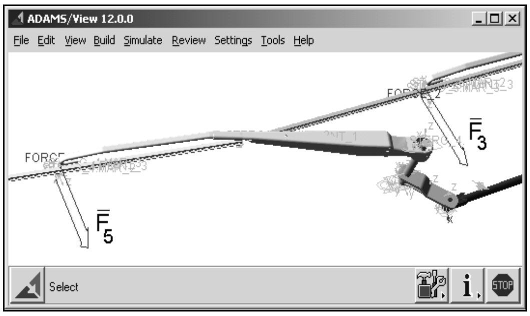


Fig. 3

In ADAMS/View, the friction force (fig. 4) was modelled using the "Function Builder", which is a versatile tool that allows creating and modifying functions.

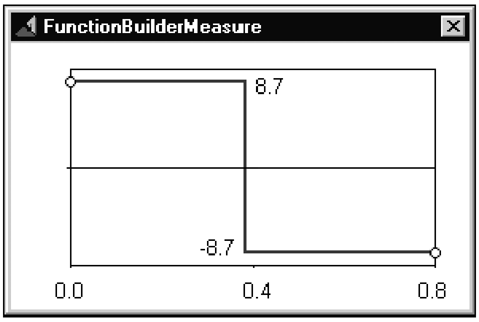
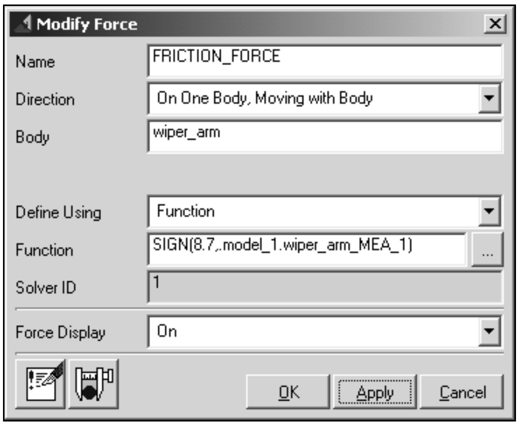


Fig. 4

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's magnitude ($F_f = 8.7$ N), and "a2" is the angular velocity of the wiper arm. In these terms, the run-time function that describes the time-history of the friction force will be (fig. 5):



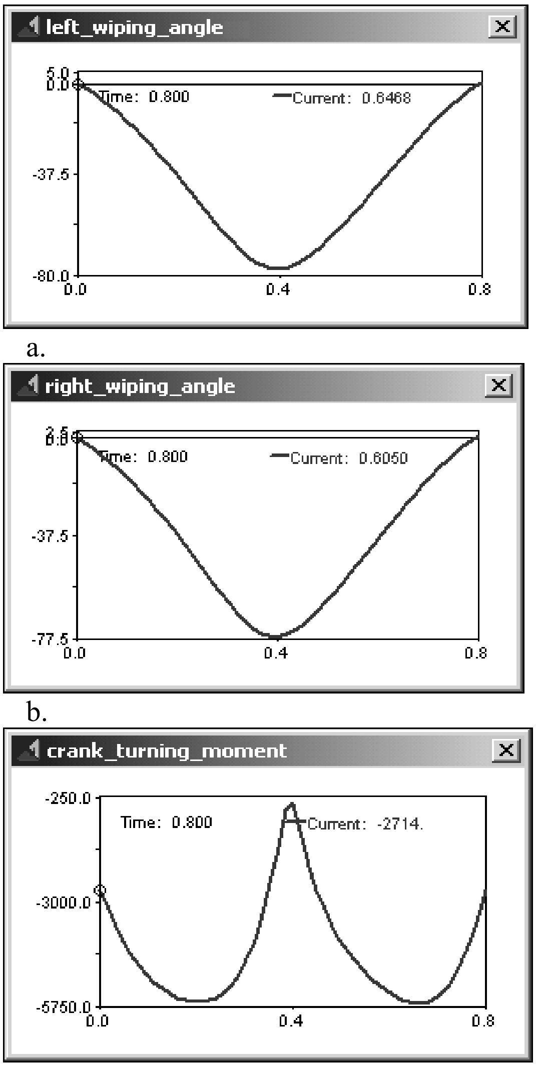
Name	FRICTION_FORCE
Direction	On One Body, Moving with Body
Body	wiper_arm
Define Using	Function
Function	SIGN(8.7,.model_1.wiper_arm_MEA_1)
Solver ID	1
Force Display	On

Fig. 5

SIGN(8.7,.model_1.wiper_arm_MEA_1) where ".model_1.wiper_arm_MEA_1" is the angular velocity of the wiper arm.

4. Results and conclusions

Analyzing the kinematic, inverse dynamic and dynamic models of the above-described wiper mechanism, a lot of results were obtained. For example, in figure 6 the wiping angles for the left and right wiper arms are presented (a, b), as well as the crank turning moment (c).



a.

b.

c.

Fig. 6

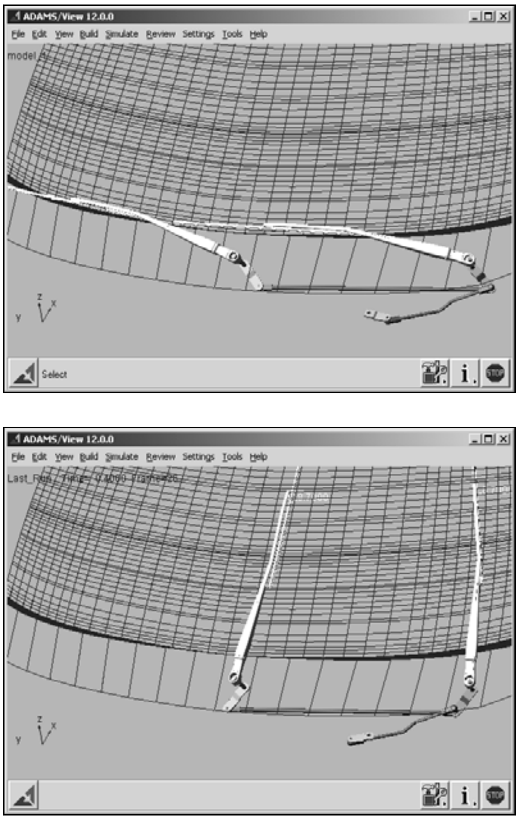


Fig. 7

At the same time, figure 7 shows two frames of graphical simulation, which were performed by ADAMS/Animation.

Using such results, the kinematic and dynamic behavior of the wiper system can be evaluated so as to obtain the optimum motion and forces characteristics.

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Analiza cinematică şi dinamică a mecanismelor ştergătoarelor de parbriz ale automobilelor

Rezumat: *În această lucrare se efectuează analiza şi simularea mecanismelor ştergătoarelor de parbriz. Algoritmul de proiectare a mecanismului ştergător implică dezvoltarea a trei modele mecanice: modelul cinematic – utilizat pentru efectuarea analizei poziţionale a mecanismului, modelul dinamic invers – pentru determinarea momentului de antrenare aplicat la pârghia motor în vederea generării comportamentului prescris cinematic, şi modelul dinamic direct – pentru evaluarea comportamentului real al mecanismului (sub acţiunea forţelor). Analiza este efectuată prin utilizarea softului MBS–ADAMS, licenţiat la Catedra de Design de Produs şi Robotică (în cadrul laboratorului CASMA).*

Cuvinte cheie: *mecanism de ghidare, punte automobil, sistem multicorp.*

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Supervizor traducere în limba engleză: Prep. Monica V. ANDREI