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MODELING AND SIMULATION AS MULTI-BODY SYSTEM OF A COMPLEX WINDSHIELD WIPER MECHANISM FOR MOTOR VEHICLES

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ABSTRACT

Once with the advent of MBS (Multi-Body Systems) software solutions, the design of mechanical systems has evolved into a new direction: the modeling and simulation of complex virtual prototypes, close to the real products both in terms of system structure and operating conditions. Accurate virtual prototypes can be built on MBS platforms with the aim to minimize the costs that would result from the experimental testing of physical prototypes. The application corresponds to a complex windshield wiper mechanism that ensures a planar motion of the wiping lamella, thus increasing the cleaned surface of the windscreen. The mechanism is defined as a multi-body system with minimum number of bodies, with the aim to reduce the complexity of the virtual model. The kinematic simulation is carried out in virtual prototyping environment, by using the MBS software solution ADAMS.

Keywords: motor vehicle, windshield wiper mechanism, multi-body system

1. INTRODUCTION

The windshield wiper systems are positioning mechanisms, their role being to ensure, on the continuous rotation of the crank-drive a series of positions on the working element - the wiping arm, which frequently behaves like a rocker (left - right oscillatory rotation). The diversity and complexity of the windshield wiper mechanisms is quite large. Various works (papers, books, patents) deal with the problem of developing automotive auxiliary systems, including windshield wiper systems (on specific components or on the whole). The importance of the windshield wiper mechanisms on the vehicle safety is being dealt with in works such as [1, 2]. Another problem encountered in the literature is related to the geometric synthesis of the windshield wiper mechanisms in order to obtain the specific movement functions [3, 4]. The growing need for driving safety requires equipping the vehicles with spatial configurations of windshield wiper mechanisms, which are capable to provide special functional requirements [5, 6].

The analysis of the windshield wiper mechanisms can be done by using automated formalisms, such as incorporated into the commercial MBS (Multi-Body Systems) software solutions, which automatically formulate and solve the motion equation systems in accordance with the specific types of constraints between bodies, or classical methods, which consist of the analytical modeling of the mechanisms, usually by geometrical or vectorial methods. Complex virtual prototypes can be created with the help of the MBS software environment, in order to obtain products that are functionally in line with high market demands. This means that it is possible to go through the correct modeling of both the system components and the operating conditions of the system, which allows the rapid testing of numerous variants in order to optimize the mechanism. This eliminates much of the experimental testing, which is an expensive and time consuming process [7].

This paper deals with the MBS modeling of a complex windshield wiper mechanism, which is formed by more kinematic loops, containing various topologies of mechanisms (linkages and gears), the simulation being performed by using the commercial MBS package ADAMS of the MSC Software.

2. THE MBS MODELING OF THE WINDSHIED WIPER MECHANISM

Unlike the most existing windshield wiper systems, where the wiping arms (one or more, usually two for the passenger cars) only perform rotational motion relative to car body, the mechanism approached in this paper allows a planar motion (rotation and translation) of the wiping arm (lamella), thus covering a larger area of the windscreen, which ensures better visibility and greater safety.

To achieve these functional performances, the mechanism that transmits the motion from the actuating element (which is a rotary motor) to the working element (i.e. the wiping lamella) has a more complex structure, including linkages and gears. Approaching such a mechanism by classical (vectorial or geometric) methods is very difficult, thus necessitating the use of automatic analysis algorithms, such that incorporated into the MBS software solutions.

The structural model of the windshield wiper mechanism is shown in figure 1. The actuating element is an electric motor that drives the crank (1) in revolute motion relative to the fixed part of the mechanism (i.e. the car body - 0). The motion is transmitted to the rocker 3 (which rotates relative to car body) by a double-loop linkage, based on three rods (2, 4, and 5). In the lower side, the rocker is connected to a planet gear (6), which engages with a fixed ring (internal) gear, the rocker acting as planet carrier. The wiping arm / lamella (8) is connected to the rocker by a translational joint, the planar motion of the lamella being controlled by the binary link (7), which is also coupled to the planet gear.

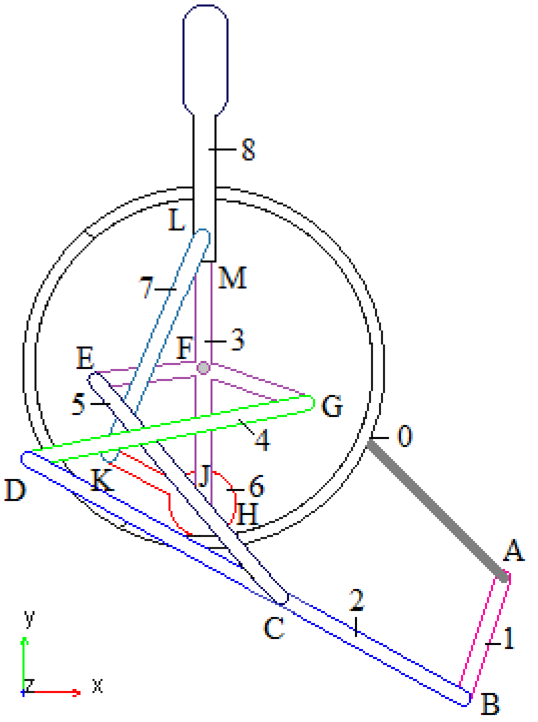

Figure 1. The structural model of the windshield wiper mechanism

The following types of joints are used to connect the above-mentioned bodies: A - revolute (adjacent bodies 1-0), B - revolute (2-1), C - revolute (5-2), D - revolute (4-2), E - revolute (3-5), F - revolute (3-0), G - revolute (3-4), H - gear (6-0), J - revolute (6-3), K - revolute (7-6), L - revolute (8-7), M - translational (8-3). In these terms, the number of degrees of mobility of the mechanism is obtained by using the Gruebler count in the planar space (S=3 - the space motion), as follows:

$$DOM = S \cdot n - \Sigma r_i = 24 - 23 = 1, \tag{1}$$

where n is the number of moving bodies (n=8), and Σr_i - the number of geometric restrictions (r=2 - revolute joint, r=2 - translational joint, r=1 - gear joint), the only degree of mobility being the revolute motion of the the driving crank, which is kinematically controlled by a motion restriction of type $\varphi_1=\varphi_1(\text{time})$, where φ_1 is the position angle of the crank.

Further, with the aim to simplify the corresponding MBS analytical model, the windshield wiper mechanism was modeled with a minimum number of bodies, thus reducing the number of unknown parameters (which define the motion of the moving bodies, in terms of location and orientation relative to the global reference frame XYZ attached to the fixed part of the mechanism), and consequently the number of equations that model the kinematic behavior of the mechanism. This feature can be assured by modeling a number of bodies as composed constraints (e.g. constant distance between two other bodies). The detailed procedure for such a modeling of the mechanical system is presented in [8], in the following being systematized the cases in which the bodies can be modeled as composed constraints, in the case of the kinematic model: the body is not fixed (only the moving parts can be subject to modeling by composed constraints); the body is not input or output element; the body has no more than two connections; the previous or the next body of the mechanism is not already modeled as a composed constraint.

Unlike the general case shown in figure 1, by the MBS modeling with minimum number of bodies, a simplified model with n=5 moving bodies is obtained (figure 2), the initial parts 4, 5, and 7 being now modeled as composed constraints of constant distance, thus obtaining:

$$DOM = S \cdot n - \Sigma r_i = 15 - 14 = 1. \tag{2}$$

The corresponding analytical model is defined by the following set of geometric constraint equations:

- the revolute joints (A, B, F, J):

$$\begin{aligned} &X_{A1} = X_A, Y_{A1} = Y_A; X_{B1} = X_{B2}, Y_{B1} = Y_{B2}; \\ &X_{F3} = X_F, Y_{F3} = Y_F; X_{J3} = X_{J6}, Y_{J3} = Y_{J6}; \end{aligned} \tag{3}$$

- the translational joint (M):

$$\begin{aligned} &(X_{M8} - X_{M3}) \cdot (Y_{M8} - Y_{M'8}) - (X_{M8} - X_{M'8}) \cdot (Y_{M8} - Y_{M3}) = 0, \\ &(X_{M8} - X_{M'3}) \cdot (Y_{M8} - Y_{M'8}) - (X_{M8} - X_{M'8}) \cdot (Y_{M8} - Y_{M'3}) = 0; \end{aligned} \tag{4}$$

- the gear joint (H):

$$\frac{\omega_6 - \omega_3}{\omega_0 - \omega_3} = \frac{|FJ|}{|HJ|}; \tag{5}$$

- the composed constraints (DG, CE, LK):

$$\begin{aligned} l_{DG} &= \sqrt{(X_{D2} - X_{G3})^2 + (Y_{D2} - Y_{G3})^2}, \\ l_{CE} &= \sqrt{(X_{C2} - X_{E3})^2 + (Y_{C2} - Y_{E3})^2}, \\ l_{KL} &= \sqrt{(X_{K6} - X_{L8})^2 + (Y_{K6} - Y_{L8})^2}. \end{aligned} \tag{6}$$

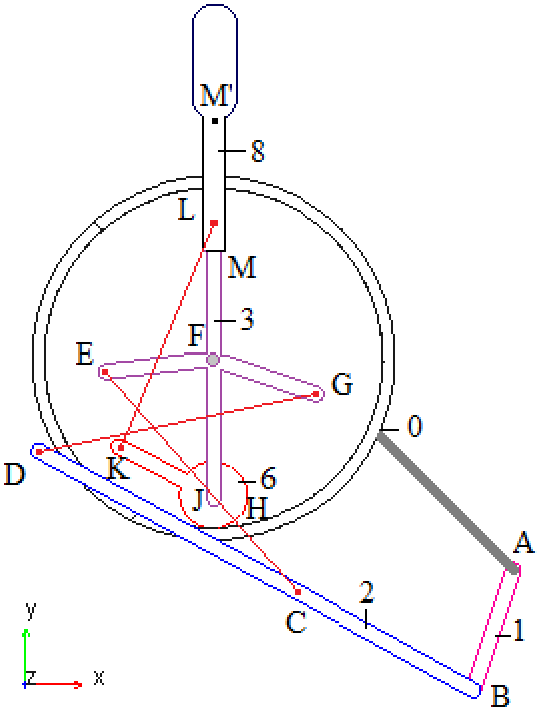

Figure 2. The MBS model with minimum number of bodies

The coordinates X_A, Y_A and X_F, Y_F are expressed in the global reference frame XYZ attached to the fixed part of the mechanism. The global coordinates of the other interest points that belong to the moving parts (e.g. P_i on the part i) are established as follows

$$\bar{r}_{Pi} = \bar{r}_{Oi} + M_{io} \cdot \bar{r}_{P(i)} \Rightarrow \begin{bmatrix} X_{Pi} \\ Y_{Pi} \end{bmatrix} = \begin{bmatrix} X_{Oi} \\ Y_{Oi} \end{bmatrix} + \begin{bmatrix} \cos\varphi_i & \pm\sin\varphi_i \\ \mp\sin\varphi_i & \cos\varphi_i \end{bmatrix} \cdot \begin{bmatrix} X_{P(i)} \\ Y_{P(i)} \end{bmatrix}, \tag{7}$$

where r_{Oi} is the position vector of the origin O_i of the body reference frame $X_iY_iZ_i$ in the global reference frame, $r_{P(i)}$ - the position vector of the point in the body reference frame, M_{i0} - the matrix that defines the orientation of the body reference frame relative to the global reference frame, φ_i - the position angle of the body. The unknowns in these equations, which will be determined through the kinematic analysis, are the motion parameters (location and orientation) of the moving bodies, namely X_{Oi}, Y_{Oi} and φ_i, while the local coordinates of the interest points ($X_{P(i)}$, $Y_{P(i)}$) are known input data.

3. RESULTS AND CONCLUSIONS

The kinematic analysis of the mechanism was performed by using the MBS software environment ADAMS. The virtual model, which is shown in figure 3, corresponds to the MBS model with minimum number of bodies (see figure 2). The three composed constraints (6) have been modeled by using the Function Builder integrated in ADAMS, based on the predefined function DM (Marker 1, Marker 2), which returns the magnitude of the translational displacement from one marker to another.

For example, the first composed constraint in equations (6), l_{DG}=ct=95mm, has been defined in the following way: DM(PART_2.MARKER_D, PART_3.MARKER_G)-95=0. The simulation was performed for a complete rotation of the crank in 3 seconds, which means that the kinematic restriction has the form φ_1 = 120°·time (the motion driver has been defined by using a rotational joint motion, which is applied in the revolute joint A of the crank to the fixed part). Among the results of the kinematic analysis conducted in ADAMS, figure 4 shows the time-history variations of the angular and linear displacements of the wiping lamella, which reflect the planar motion of the lamella, thus increasing the cleaned surface of the windshield.

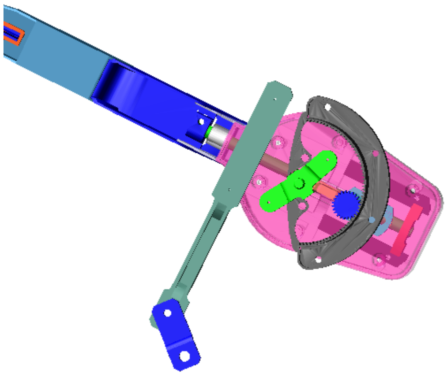

Figure 3. The MBS virtual model of the windshield wiper mechanism

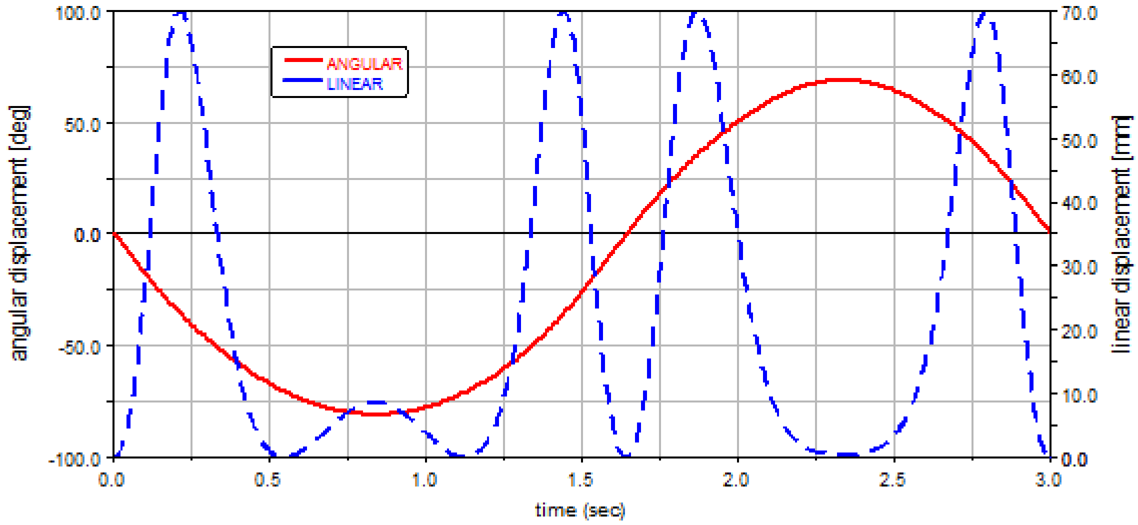

Figure 4. The angular and linear motions of the wiping lamella

The application presented in this paper is an enlightening example of the possibilities offered by the MBS technique in the design of complex mechanical systems. High accuracy virtual prototypes can be built by using such a modeling & simulation technique, with the aim to reduce the costs that would result from the design of hardware prototypes, as well as the time required for experimental testing.

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