Computer Aided Analysis of Dynamic Torque of Door System

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ABSTRACT

In this paper, CAMD(Computer Aided Multibody Dynamics) method is used to find the dynamic torque for a given elevator door system. The conventional expressions for the torque is considered first and the proposition for the new approach is discussed. The computational algorithms for the dynamic torque analysis of a given door system is proposed using inverse dynamics which is actively applied in the field of robotics, and CAMD method which is widely used in Vehicle dynamics. The possibility of the proposed method is examined for the application of a real door system.

1. INTRODUCTION

The door is one of the important factor of the elevator for the passengers. The open and close operation's speed pattern and vibration is the performance seen by the passenger. The collision of the passenger on close operation is the impact felt by the body and is the door's performance. The number of door movement is the twice that of the operation of the elevator. The movement of the door is the most sensitive part as seen by the passengers. The importance of the door can be revealed in door related claim which is more than 40% of the elevator service(maintenance).

The door system of the elevator can be classified by the mechanical mechanism and electrical control. The mechanism is designed first and the drive is then selected. Generally, the driver is the electric motor, and the trend is to move from a D.C motor to an A.C motor which uses an inverter. Also in order to guarantee the performance of the door, suitable controller is used. The method using the D.C motor used variable resistors or thyristor to control the voltage. However with the use of an A.C motor and the inverter vector control method, a more precise control can be obtained.

In order to drive the motor at a desired speed pattern the time history of the dynamic torque is the most significant factor. So far, the door system has used modeling of one body and used its corresponding moment and torque to get a governing equation. But these equations are geared to find the values of the rated torque rather than the time history of the torque. Also depending on the system, the equations have to be made differently, and even within the same system different equations have to be made to obtain the information about different bodys of the system.

In this paper, CAMD method which is widely used in the field of vehicles[1] and inverse dynamic which is used in the field of robotics[2] are applied to the door system to find the time history of the dynamic torque.

2. CONVENTIONAL METHODS

In order to predict the methods for the dynamic torque, the complex door system is simplified as a rotating body as shown in Fig.1. Also in order to show the effect of mass distribution of a rotating body the relative equations for the kinetic energy is used such that

$$I_D = I_L + I_A \tag{1}$$

where I_L = equivalent mass moment of inertia for a body of linear motion

I_A = equivalent mass moment of inertia for a body of angular motion

The operative resistance of the door system is represented by the resistance torque of the motor about its axis as shown in Eq.2.

$$T_R = \frac{n}{R} \cdot F_R \tag{2}$$

where n = velocity ratio.

R = transmission ratio[3].

F_R = resistance force acting upon the door. (For example, the force acted upon by the closer, the force between the door rail and the door hanger)

If the equation for the dynamic torque, so far explained, is summarized [4], then

$$T_M = \frac{1}{\eta}\left(I_D \frac{d\omega_M}{dt} + T_R\right) \tag{3}$$

where ω_M = the angular velocity of the motor.

η = mechanical efficiency of the system.

3. CAMD METHOD

Before the uses of computers, one rigid body or system of particles has only been analyzed in dynamics. By 1960 the situation has changed by digital computers. It has been possible to calculate the large amount of computations. Further change has occurred because of the development of the space navigation. It has not been possible to ignore the characteristic of the multibody when spacecraft is designed. Hence the demand for the multibody system analysis has increased.

Compare to the calculations which were so far relied upon simplified formulas, the multibody system analysis is much dependent on the computers and is called CAMD. The CAMD is at present actively researched in Space Dynamics, Vehicle Dynamics and Robot Dynamics.

3.1 Generalized Coordinates

In order to describe the mechanics of the body the frame is first considered. Fig 2 represents the body within a frame. In Fig.2 the {0} represents the absolute frame and is the reference point for all under consideration. The {i} represents the body frame attached onto the i-th body and is very useful to show the information about the body. The information about the position of the body and angle within a system is represented by the generalized coordinate. The generalized coordinate of a body within a plane is as shown below.

$$q_i = \begin{bmatrix} r_i \\ \phi_i \end{bmatrix}_{3\times 1} \tag{4}$$

where r_i = 2×1 position vector of {i} with respect to {0}

ϕ_i = the scalar of the angle of {i} with respect to {0}.

The generalized coordinate of multibody system consisting of number of body (nb) is as shown below.

$$q = \left[q_1^T, \;\cdots\; ,q_{nb}^T\right]^T_{3nb\times 1} \tag{5}$$

3.2 Constraint

Door system is interconnected by the joint. Rotation of the motor controlled by the velocity pattern is converted into linear movement of door. The constraint condition within a door system can be largely classified as kinematic constraint and driving constraint. The kinematic constraint is generally constrained by the joint. Also the driving constraint is generally constrained to allow movement of a particular body.

In order to model the relative movement of the body the constraint equation is used. Generally, the constraint equation is expressed by the generalized coordinate and unlike driving constraint the kinematic constraint is independent of time.

Kinematic Constraint

Kinematic constraint of the door system is classified as joint constraint and ground constraint. The joint constraint is determined by type of the joint. The rotational and translational joint are used for modeling of the plane movement of door system.

The rotational joint is a source for restricting the relative angular movement along the axis of the two bodies, and is used for connecting the two links.

The translational joint is a source for restricting the relative linear movement along the axis of the two bodies, and is used for modeling the linear movement between the door panel and its rail in a door system. The ground constraint is used for modeling the body where its position is fixed with respect to time. In this paper the door machine base is used as ground for modeling.

Driving Constraint

In order to allow the movement of a particular body the driving constraint is used. Generally, the motor is used for the circular movement in a door system. The restricted angular movement of the body dependent on time is modeled by the angular driver. In order to obtain a simulation for the time history of dynamic torque of a door system, time history of driver angle of curve data from motor's RPM pattern are used as input.

3.3 Kinematic Analysis

The aim of kinematic analysis is to obtain the position, velocity, acceleration of a system, and can be analyzed by the constraint equation of a system. Constraint equation is differentiated with respect to time the velocity equation can be obtained and if it is differentiated further then acceleration equation can be obtained.

Position Analysis

The following shows the equation representing the restrictive condition of the system[5].

$$\Phi(q,t)=\begin{bmatrix}\Phi^K(q)\\ \Phi^D(q,t)\end{bmatrix}_{3nb\times 1}=0 \tag{6}$$

where $\Phi^K(q)$ = kinematic constraint

$\Phi^D(q,t)$ =driving constraint

Generally, the door system operates by a motor and hence $\Phi^K(q)$ represents $(3nb-1)\times 1$ vector and $\Phi^D(q,t)$ is a scalar.

In analysis of inverse dynamic of a door system for obtaining the dynamic torque, time history of angle of the motor axis can be found from motor RPM pattern, and using Eq.6 the generalized coordinate for system can be obtained. This process is called position analysis.

Velocity Analysis

Equation 6 is differentiated with respect to time, kinematic velocity equation as in Eq.7 can be obtained.

$$\dot{q}=-\Phi_q^{-1}\Phi_t \tag{7}$$

Here, Φ_q is $3nb\times 3nb$ Jacobian matrix and defined as $\Phi_q\equiv\frac{\partial\Phi}{\partial q}$. Φ_q^{-1} is the inverse of Jacobian matrix Φ_q. Φ_t is the derivative of constraint equation Φ with respect to time t. The process of obtaining $\dot{q}$ by Eq.7 is called velocity analysis.

Acceleration Analysis

If Eq.7 is differentiated with respect to time, the kiematic acceleration equation as in Eq.8 can be obtained.

$$\ddot{q} = -\Phi_q^{-1}\gamma \tag{8}$$

γ is as shown below.

$$\gamma = \dot{\Phi}_q\dot{q} + \Phi_{tt} \tag{9}$$

Here, Φ_{tt} is second derivative of the constraint equation Φ with respect to time t. By equating q and $\dot{q}$, derived from position and velocity analysis to Eq.8, the process of obtaining $\ddot{q}$ is called acceleration analysis.

3.4. Inverse Dynamics

When a force acting upon a system is known, the movement of the system is explained by dynamic analysis, the calculation process for the force required to apply the fixed movement is called inverse dynamic analysis. The inverse dynamics is required for the design of a control system with which the information is provided by the driving force and torque, or is used to select the motor for such system. Within a door system design the inverse dynamics is used to calculate the motor capacity where the motor operates on a door by the velocity pattern.

Closer

Closer is a safety device for closing the landing door. Closer is operated by an external force and acts as a resistant to opening the door. When closing the door, it reduce the load torque. If the force developed by the closer is called f, and the distance between the two points operated by the closer is called ℓ, the generalized force operated on the system is as follows.

$$\begin{aligned}\delta W &= -f \cdot \delta\ell \\ &= Q_i^T\delta q_i + Q_j^T\delta q_j\end{aligned} \tag{10}$$

Here, Q_i and Q_j represents generalized force operated on the center of mass of body i and body j by the closer.

Lagrange Multiplier

The dynamic equation of multibody system which has constraint condition is as follows[5].

$$M\ddot{q} + \Phi_q^T\lambda = Q \tag{11}$$

Here, $M = \mathrm{diag}(m_1, m_1, J_1, m_2, m_2, J_2, \ldots, m_{nb}, m_{nb}, J_{nb})$,

m_i = mass of i-th body,

J_i = mass moment of inertia of i-th body.

Q = generalized force,

λ = Lagrange multiplier.

The Lagrange multiplier is written as Eq.12.

$$\lambda = \left(\Phi_q^T\right)^{-1}\left(Q - M\ddot{q}\right) \tag{12}$$

Dynamic Torque

In Eq.11 $-\Phi_q^T\lambda$ represents the constraint reaction force acting on the center of mass. However, for solving the constraint reaction force and torque at constraint point, virtual work theory is used.

$$-\left(\delta r_i^T \Phi_{r_i}^T \lambda + \delta\phi_i \Phi_{\phi_i}^T \lambda\right) = \delta r^T F + \delta\phi_i T \tag{13}$$

Here, F and T represents the reaction force and torque on the constraint point.

If the position vector to the constraint point is called r then,

$$r = r_i + A_i s_i' \tag{14}$$

If variation of Eq.14 is equated to Eq.13 the values of F and T are as shown in Eq.15.

$$\begin{aligned} F &= -\Phi_{r_i}^T\lambda \\ T &= \left(\left(B_i s_i'\right)^T \Phi_{r_i}^T - \Phi_{\phi_i}^T\right)\lambda \end{aligned} \tag{15}$$

In order to calculate the dynamic torque of a door system the Eq.15 is used to calculate the reaction torque from the driving constraint reacting on a body, and this reaction torque T operating on the door system is called the dynamic torque.

3.5 Computer Implementation

The method to calculate the dynamic torque operating on a door system using CAMD method from RPM pattern is as follows.

Step 1: Read input data and set initial time.
Step 2: Solve Eq.6 to obtain the position information
Step 3: Solve Eq.7 to obtain the velocity information
Step 4: Solve Eq.8 to obtain the acceleration information
Step 5: Solve Eq.15 to obtain the constraint reaction force and torque.
Step 6: If final time is reached, then terminate; otherwise $t = t + \Delta t$, and go to step2

4. EXAMPLE

4.1 Door System

Fig.5 represents the center open type door system set up on a test frame in order to validate the feasibility of the CAMD method. The rotation developed from the motor converts into linear movement of the door by the reduction pulley and link. Also the closer, attached on to each end of the door operates as resistant to the movement of the motor when the door is opened, and when closing the door reduces motor load so acting as a safety device to closing the door.

Calibrating equipment and items are as follows. The torque sensor, placed between the motor and its pulley is used to measure the motor RPM and dynamic torque, and tacho generator was placed at the center of the door panel to calculate the door velocity. Fig.6 shows CAMD model of the door system. The movement between the links is modeled by rotational joint and the movement between the door and its rail is modeled by the translational joint. The motor and reduction pulley is modeled by the angular driver. The closer is fixed by the spring element. The Table 1 shows the summarized version of CAMD model.

	number	d.o.f/each	d.o.f
body	14	+3	+42
rotational joint	17	-2	-34
translational joint	2	-2	-4
driving constraint	1	-1	-1
ground constraint	1	-3	-3
spring element	2	0	0
system			0

Table 1 Modeling

4.2 Results

Fig.7~Fig.12 shows the results of computer simulation and experiment of actual door system. Experiments were performed on open and close condition, and identical scale was used for identical items for comparative purposes.

Fig.7 and Fig.8 shows RPM of the motor. The calibrated data from the practical model was input by using the angular driver of CAMD model. Fig.9 and Fig.10 shows the velocity of the door. The reason for the vibration in experimental result was due to imperfect surface condition and the vibration of jig, fixing the tacho generator. Fig.11 and Fig.12 shows the dynamic torque.

5. CONCLUSIONS

This paper proposed an appropriate computational algorithm for dynamic torque analysis of the door system using inverse dynamics which is widely used in CAMD technique and Robot dynamics. The conventional method for the analysis of the torque is considered, and the proposed method is verified using the practical door system tests and analysis. From the research the following conclusions were obtained.

- The conventional method is a special purpose program which is only used on a particular model, and in order to analyze the door system containing different mechanisms, the equations has to be reanalyzed.

- CAMD method is a general purpose program. which the input only has to be changed depending on the model, and hence many different types of the door mechanism can be analyzed.
- The conventional method provides only the information about the dynamic torque and to obtain different information requires new equations to be incorporated.
- CAMD method uses the same equations for dynamic torque, position of the body, speed, acceleration and force acting on a joint. and they can be calculated at once.

The above considered only the analysis point of the equations. However if the equations are considered from the point of the user it is as follows. The conventional method can be applied directly in the laboratory or on the site. But CAMD method requires the knowledge of multibody dynamics and is slightly more complex. However, in multibody dynamics many commercial programs are available to compensate for this by providing preprocessors and postprocessors.

6. REFERENCES

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7. BIOGRAPHY

Sang Hoon SHIN received the B.S, M.S and Ph.D. degrees in Mechancial engineering from Pusan National University in 1987, 1989, 1995 respectively. He joined LG Industrial Systems Co. in 1995 and worked on development of door system in Building Systems R&D Lab.

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Wan Suk YOO received the Ph.D degree from the University of Iowa in 1985. He is now professor of the Mechanical Engineering Dept. of Pusan National University. His research interest are flexible multibody dynamics and vehicle dynamics.

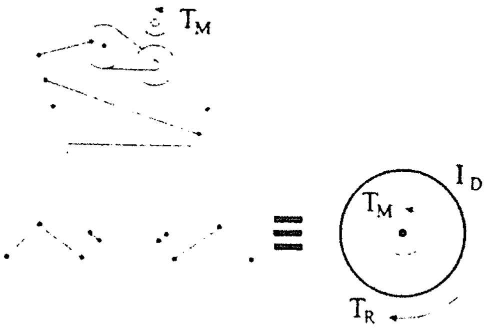

Fig.1 Previous Method

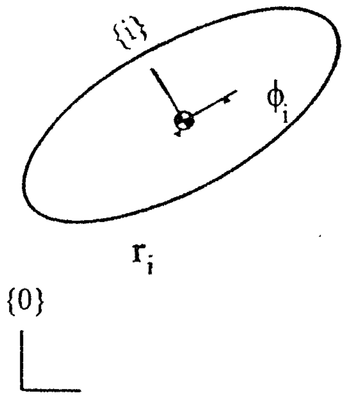

Fig.2 Body Configuration

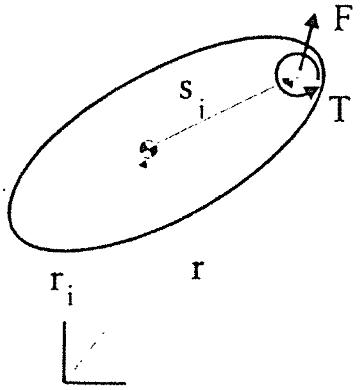

Fig.3 Constraint Reaction Force

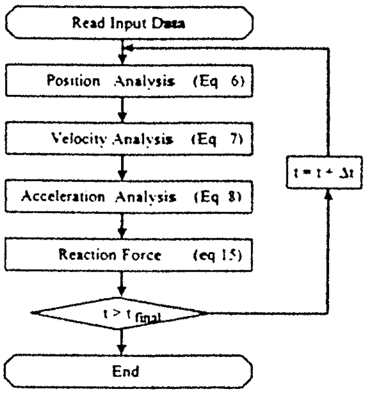

Fig.4 Computational Algorithm

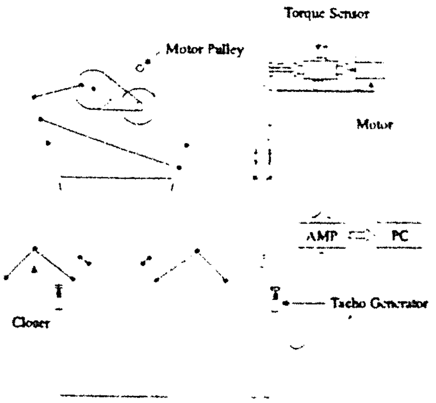

Fig.5 Door System

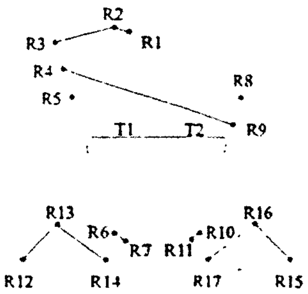

Fig.6 CAMD Model

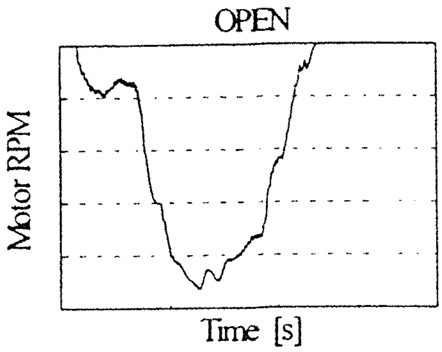

Fig.7 Motor RPM (OPEN)

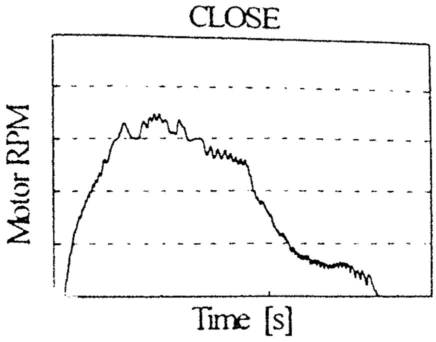

Fig.8 Motor RPM (CLOSE)

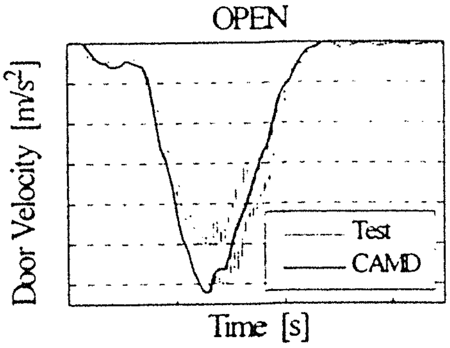

Fig.9 Door Velocity (OPEN)

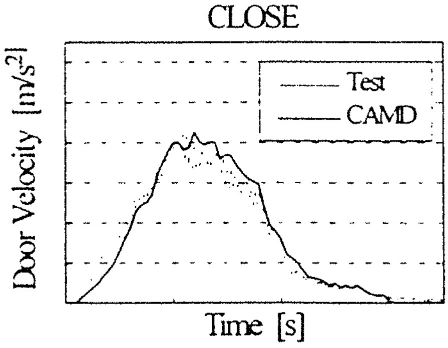

Fig.10 Door Velocity (CLOSE)

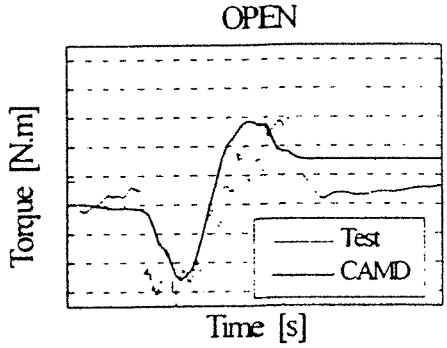

Fig.11 Dynamic Torque (OPEN)

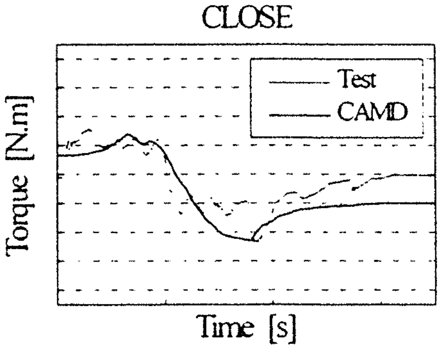

Fig.12 Dynamic Torque (CLOSE)