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ANALYTICAL AND COMPUTER AIDED POSITIONING, VELOCITY AND ACCELERATION ANALYSES OF HINGE MECHANISM OF LARGE VEHICLE TAILGATES

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ABSTRACT

Hinge mechanisms of vehicles can be designed and manufactured in various ways in the automotive industry. The hinge mechanisms serve in assembling of tailgates, which are operated manually or automatically and expected to fulfil the functions such as lockability during vehicle service life, strength, impermeability etc., to vehicle bodies. In this study, a new alternative design of tailgate hinge mechanism was proposed in order to remove the shortcomings of the mechanisms used at the current bus tailgates. Positioning, velocity and acceleration analyses of the proposed mechanism were conducted as analytically and computer aided. In addition, the prototype productions of new hinge mechanism were applied to Skyliner model buses which are produced at MAN Türkiye A.Ş.. Moreover, the applicability of the new hinge mechanism into different applications were discussed in terms of the criteria such as easiness of opening and closing of the tailgate under ordinary and extraordinary loads, strength of mechanism in response to weight reduction efforts etc. by the findings obtained.

Keywords: *Bus Tailgate, Hinge Mechanism, Analytic and Computer Aided Analysis.*

INTRODUCTION

Hinge mechanisms of vehicles can be designed and manufactured in various ways in the automotive industry. The hinge mechanisms are assembled into rear doors and tailgates such a way that they can be operated manually or automatically. The mechanisms utilised at rear doors and tailgates are manufactured in such a manner that they are expected to fulfil the functions such as lockability, impermeability, strength, and durability throughout the life cycle of the product.

Yıldız et al. [1] studied static analysis of a gas cylinder operated tailgate mechanism in passenger cars and calculated the hand force required in opening and closing the tailgate. Duran [2] conducted positioning analysis for boot doors used in five-door-vehicles by the help of Burmester theory and the volume of working envelope during door opening was lessened. Baykuş [3] designed and analysed a new mechanism for the tailgate of passenger carrying vehicles that the vehicles were originally designed for trading purposes. On the other hand, Swamy et al. [4] studied on rigid body dynamics calculation for an industrial robotic manipulator arm and investigated the effects of loads and torques applied to the arm on degree of movement in the system. Zhang et al. [5] calculated total loads imposed to a robotic manipulator and torques effected to hinges and computer aided analysis of the manipulator was accomplished.

The studies conducted on baggage compartment doors and tailgates mechanisms were generally gathered around whether the mechanisms carried the weight of door, the occupied surface area, and the related analyses. Nowadays, the assessment of requirements that arisen based on regulations and shortcomings originated after use as well as ergonomics features requirements are come to the fore. The components that provide service in buses such as baggage compartment doors and tailgates can be deformed in due course due to design and environmental conditions and, thus, they can be cause of customer dissatisfaction and threaten travel safety. For this reason, it has become a necessity nowadays that the baggage compartment doors and tailgates of buses should be designed as suitable for continuous use and ergonomically.

In this study, a new hinge design was proposed for a bus tailgate mechanism which led to deformation over time and was not ergonomic. The analytic and computer aided positioning, velocity and acceleration analyses belonged to the proposed mechanism were accomplished. The data obtained were compared and it was found that the applied two methods were verified one another. By the new design of the mechanism, it was determined that an improvement on the distance of door opening stroke, which was seen as a shortage in the ergonomic features, was obtained and the deformation, which occurred at the door over time, was prevented by the cycle controls. A prototype was manufactured and assembled into bus frame, thus, the functionality of new hinge mechanism was examined.

NEW ALTERNATIVE HINGE MECHANISM

New hinge mechanism developed was given in Fig. 1. Two platforms were used to assembly mechanism into tailgate and vehicle body. The ribs with movement freedom of mechanism bars in X-Z direction were accommodated on the platforms. When the tailgate closed the angle between two platforms was set to 90° (see Fig. 2). While the tailgate entirely opened the angle was reached to 186° (Fig. 3). The new developed mechanism possessed six pin axes and these pins were able to carry tailgate weight and the loads imposed to tailgate.

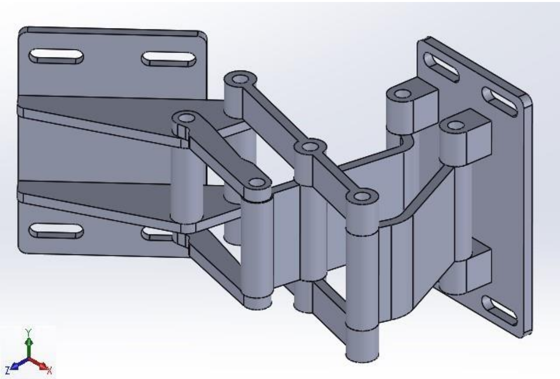

Fig. 1. New hinge mechanism

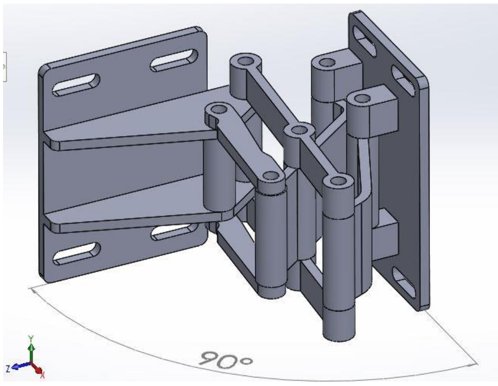

Fig. 2. Closed tailgate (initial position)

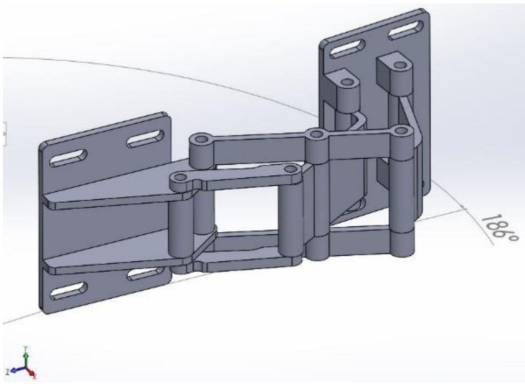

Fig. 3. Opened tailgate (final position)

CONDUCTED ANALYSES

Analytic Analyses

The equations employed for solutions of positioning, velocity and acceleration of mechanisms were the equations with complex numbers in the literature [6, 7]. The analytical solution of equations were accomplished by using a spreadsheet application, and the graphs were obtained according to the geometrical boundaries of the mechanism [8]. The environmental conditions were also dismissed. The masses and frictions values in the solutions of positioning, velocity, and acceleration analyses were omitted. By the annotation depicted in Fig. 4, the positioning, velocity and acceleration changes between the initial position and final position of the mechanism were calculated based on the positioning, velocity and acceleration equations (Eqs. (1)-(6)) that were prepared for two different region of the mechanism (I and II) and by applying the solution methods in the literature [9].

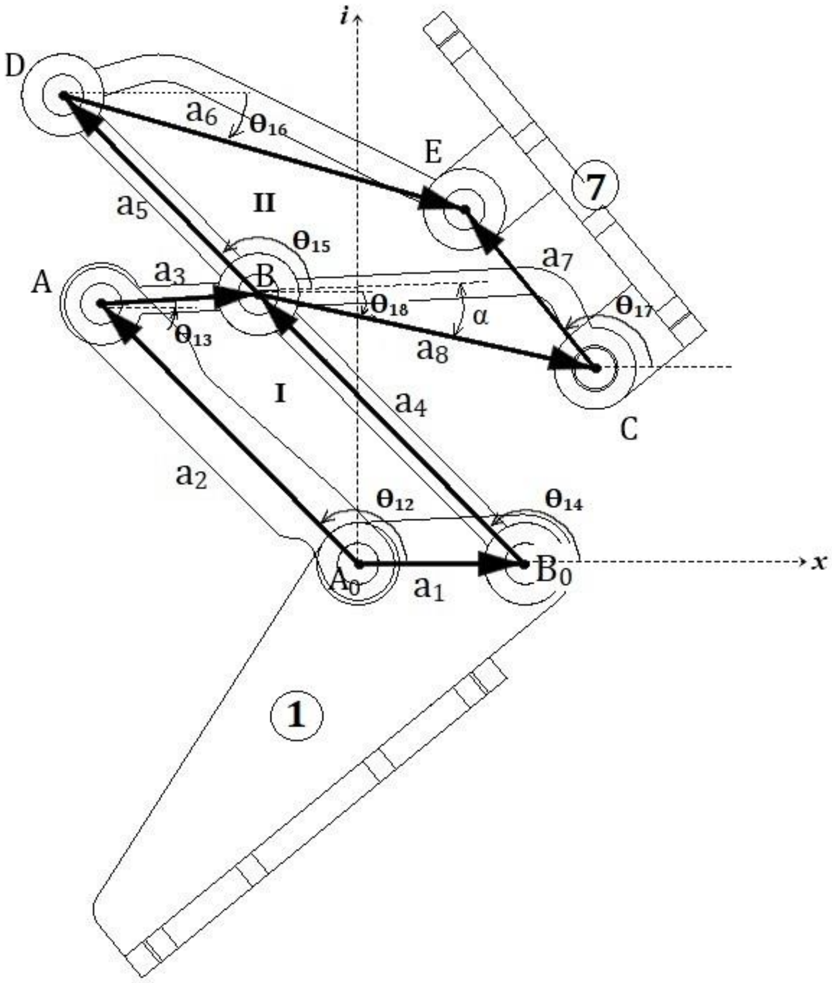

Fig. 4. Annotation used in four bar mechanism

Positioning equation for the region of #I for (1, I),

$$a_2.e^{i\theta_{12}} + a_3.e^{i\theta_{13}} = a_1 + a_4.e^{i\theta_4} \tag{1}$$

and positioning equation for the region of #II for (1, II),

$$a_5.e^{i\theta_{15}} + a_6.e^{-i\theta_{16}} = a_8.e^{-i\theta_{18}} + a_7.e^{i\theta_{17}} \tag{2}$$

were formed. When Eq. (1) was derived for the region of #I for (2, I),

$$\theta'_{13} = \omega_{13} = \omega_{18} = \frac{a_2}{a_3}.\frac{sin(\theta_{12}-\theta_{14})}{sin(\theta_{14}-\theta_{13})}.\omega_{12} \tag{3}$$

and, similarly, when Eq. (2) was derived for the region of #II for (2, II),

$$\theta'_{14} = \omega_{14} = \omega_{15} = \frac{a_2}{a_4}.\frac{sin(\theta_{12}-\theta_{13})}{sin(\theta_{14}-\theta_{13})}.\omega_{12} \tag{4}$$

velocity equations were obtained. When velocity equations were derived to provide the acceleration equations for the region of #I for (3, I),

$$\theta_{13}'' = \alpha_{13} = \frac{\omega_3}{\omega_2} \,.\alpha_2 - \frac{a_2 \,.\, \omega_2{}^2 \,.\, \cos\delta + a_3 \,.\omega_3{}^2 \,.\cos\varepsilon + a_4 \,.\omega_4{}^2}{a_3 \,.\sin\varepsilon} \quad (5)$$

was found. Similarly, the acceleration equation for the region of #II for (3, II) was obtained as follows.

$$\theta_{14}'' = \alpha_{13} = \frac{\omega_4}{\omega_2} \,.\alpha_2 + \frac{a_2 \,.\, \omega_2{}^2 \,.\, \cos\gamma + a_3 \,.\omega_3{}^2 + a_4 \,.\omega_4{}^2 \,.\cos\varepsilon}{a_3 \,.\sin\varepsilon} \quad (6)$$

Here, an attention was paid to $\theta_{15} = \theta_{14}$ and $\theta_{18} = \theta_{13} - \alpha$; $\theta_{15}^{'} = \theta_{14}^{'}$ and $\theta_{15}^{''} = \theta_{14}^{''}$ and $\theta_{18}^{''} = \theta_{13}^{''}$ for solution of the region of #II equations.

The equations were solved considering that the mechanism was assembled into the vehicle body by the element of #1 and the tailgate by the element of #7. The graphs of positioning, velocity, and acceleration of the tailgate, which were obtained from analytic solution, as follows (see Fig. 5-7).

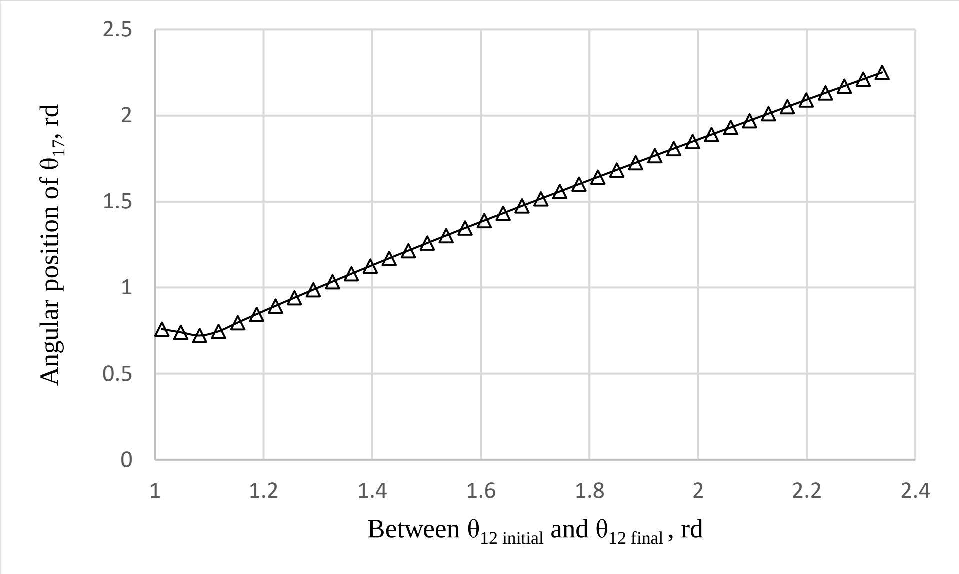

Fig. 5. Angular positioning change of θ_{17} relative to θ_{12}

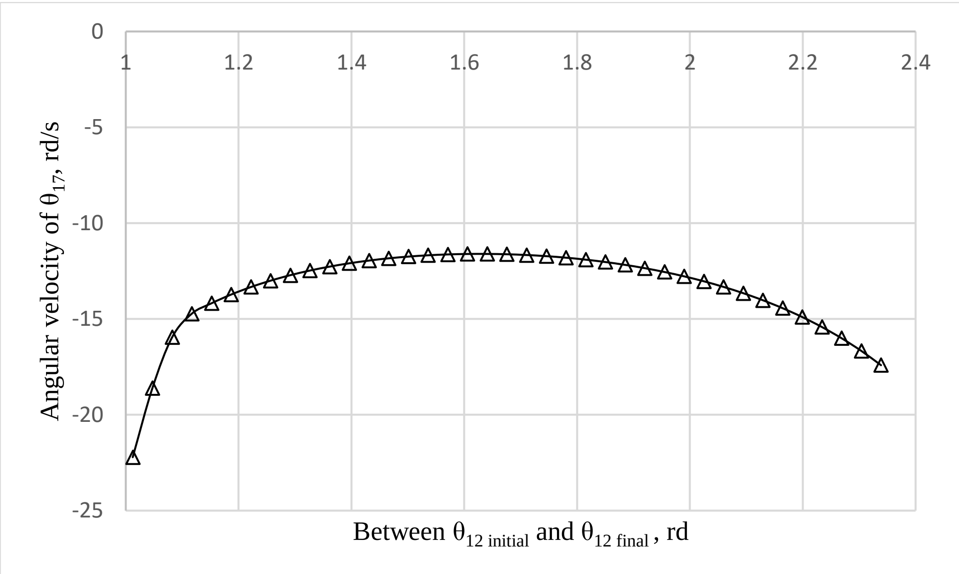

Fig. 6. Angular velocity change of θ_{17} relative to θ_{12}

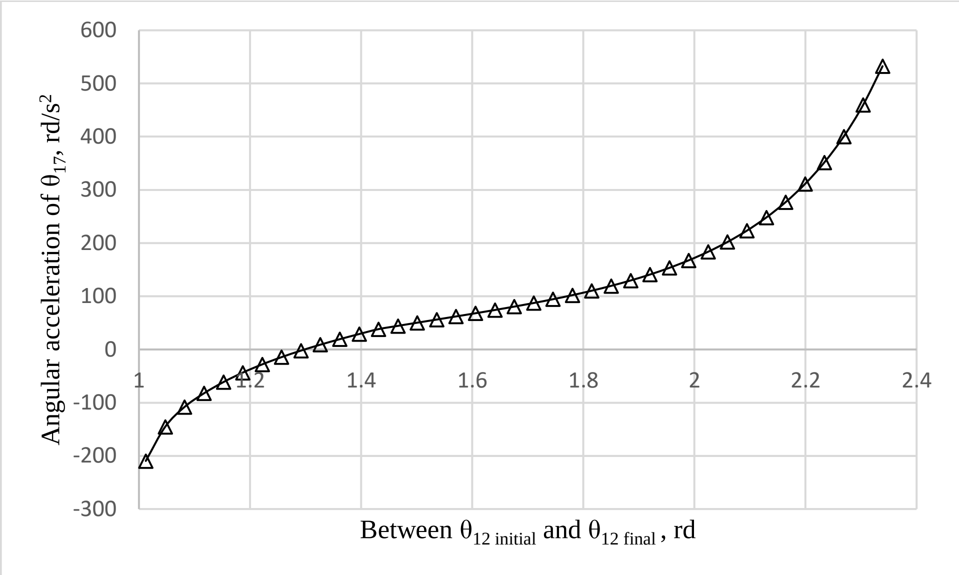

Fig. 7. Angular acceleration change of θ_{17} relative to θ_{12}

When the graphs were examined, it was seen that the tailgate reached the highest angular velocity at θ_2=1.64 rd (93°) and the highest acceleration at θ_2=2.33 rd (134°). These positions, which the highest angular velocity and the highest acceleration were obtained, should be taken into account in force analysis. The attention should be given that the material was not yet assigned and mass, friction, and shock absorber were not attached into the mechanism.

Computer Aided Analyses

The hinge mechanism was modelled in SolidWorks, which was well known computer aided design and analysis program, and the analyses of positioning, velocity, and acceleration were accomplished in Motion Analysis module of the program (see Fig 8-10).

It was seen that the results obtained from analytic analyses were in harmony with the solution received from computer aided analyses. The units of X and Y axes at the graphs prepared by analytical analyses were in θ, rd, while the X axes were in time, s, and Y axes were θ, θ/s, and θ/s^2, respectively, for the graphs obtained by computer aided analyses. Although the measurable differences at X axis the graphs of analytical and computer aided solutions, the highest angular velocity was found at θ_2=1.64 rd, t=1.1 s, and angular acceleration was obtained at θ_2=2.33 rd, t=1.9 s. While the lowest angular velocity was received at θ_2=1.01 rd, t=2 s, and angular acceleration was incurred at θ_2=1.01 rd, t=2 s.

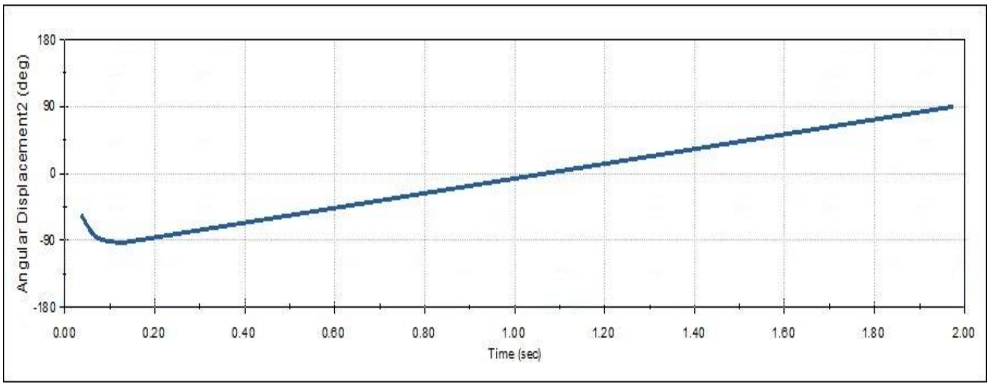

Fig. 8. Angular positioning of tailgate

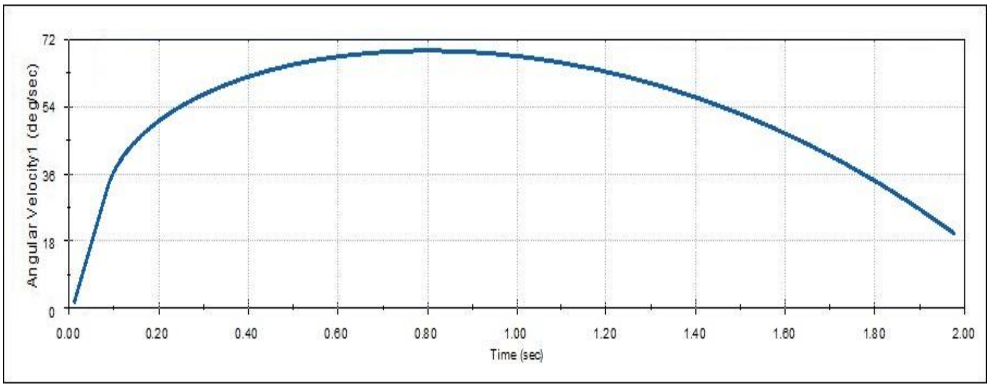

Fig. 9. Angular velocity of tailgate

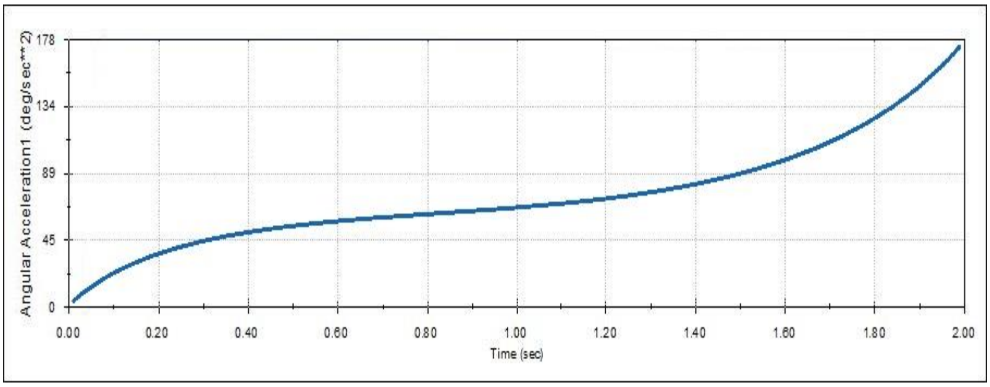

Fig. 10. Angular acceleration of tailgate

PROTOTYPE PRODUCTION OF HINGE MECHANISM

The prototype mechanism was produced at MAN Türkiye A.Ş. and it was assembled in door test frame as seen in Fig. 11. The material of AISI304 (EN X5CrNi18-10) was chosen for new hinge mechanism due to its easy weldability and high corrosion strength properties.

Fig. 11. New mechanism assembly on tailgate

RESULTS ANS DISCUSSION

Design of the proposed hinge mechanism was examined in terms of positioning, velocity, and acceleration changes of mechanism members. It was proved that the mechanism become a suitable model to bus tailgate by considering various number of opening and closing cycles in its limit conditions.

It was accepted that the graphs obtained in analytic and computer aided positioning, velocity, and acceleration analyses were in harmony. In future study, dynamic force analysis will be performed for revealing the joint loads and the joint sizes will be verified.

CONCLUSIONS

In this study, a new design of a hinge mechanism for large vehicle tailgates was proposed. The findings obtained after analyses showed that the mechanism was suitable to application and supported to the lightening study on total weight of vehicle, which the new mechanism was lighter than of previously employed hinge mechanism. It was observed that there was no unfavourable effect in opening and closing course. The prototype of new hinge mechanism also showed that the mechanism became a case in which it could be used at the vehicle baggage compartments and tailgates in automotive industry. The rescaling and reanalysing options, which computer aided design and analysing environment present, provide designers highly valuable opportunities based on the variations on weight and size of tailgate [10].

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NOMENCLATURE

θ	Angular position, rd
θ'	Velocity, rd/s
$\theta'' = \omega$	Acceleration, rd/s^2

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