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An Investigation of Working Principles and Developing Mechanical Systems of Passenger Doors of Commercial Vehicles

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Abstract

One of the main elements in public transportation vehicles used in the automotive sector is the gates. The convenience of in-car comfort in commercial vehicles, suitability for the purpose of use, and opening and closing of the doors are extremely important. For this reason, mechanical systems of doors constitute a very important research area. In this study, the outward electrical opening, double-wing passenger door mechanical systems used in commercial vehicles were examined, and various improvements were made. For the advantages of design changes; Road tests, bench tests, CAE analyses, and torque-amperage measurements were performed. The results obtained from the tests were modeled in CAD environment, and CAE analysis was performed and compared with the results obtained from the tests. According to the results of the tests, the deflection values of the passenger door connection bracket were reduced, and a reduction in the deflection value was achieved by approximately 70%. Rigidity increased at the passenger doors. Measuring the torque values that the doors are exposed to during operation has made it easier to monitor and simulate the vehicle operating conditions.

Keywords - *Commercial Vehicle, Passenger Door, Electric Door, Test, CAE*

I. INTRODUCTION

One of the most important functional elements used in public transport is passenger doors. It is a very important research area to examine, study, and develop in terms of timeliness and comfort of commercial vehicles in terms of providing both in-vehicle comfort and suitability for the purpose of use. In these systems, models with multiple different working principles are used. Some of these models are passenger doors consisting of electrical, pneumatic, and mechanical systems. Many types of research are carried out by designers about the improvements in passenger doors, and different models are being developed. Improvements such as drive systems, optimization of opening-closing times, sealing and improvements in passenger doors are among the most Researched and developed issues. Due to the commercial competition in the automotive sector and the necessity to produce high-quality products in terms of compliance with international standards, researches on the doors which are the main element in public transportation vehicles are continuing intensively. In the study conducted by Katz and friends (2012) on the study of the working principles of the wing doors of commercial vehicles and the development of mechanical systems, it was examined how the bus design factors affect the crowd in front of the door (densities). It has been shown how this accumulation has an impact on passenger safety. These results are based on data collected for 2,807 stops in Dhaka, Bangladesh. Clumps and densities occurring in front of the door were affected by multiple bus design factors such as vehicle length, front seating area, and service type, including door layout, corridor. Wang (2015). In this research, he designed a 1: 3 scale prototype door for the Spartan Superway project and made tests for this door. In the research, general principles related to door design are included. Parmashwar et al. (2015) investigated the numerical analysis of hinges used in the driver's gates. Examples of finite element method (FEA) analysis of door hinges modeled by Solidworks program are presented. Studies on the numerical analysis logic of hinges used indoors are included. Jun 2010. In this study, which is examined in bus type vehicles, passenger doors are examined as a section. In this study, the working principles of the passenger doors of Volvo brand buses are examined.

In the study carried out by the Swedish transport ministry, options were presented along with the mandatory features that should be in the minibusses and buses used for public transportation. Even though reference is made to the regulation of UN-ECE-R107, it has detailed information about door opening-closing, door area properties (location, coating information, etc.) (Buss, (2014). Source, (2016) pneumatic used in public transportation It has gathered information about devices developed for measuring and preventing air losses in systems (brakes, doors, etc.).

In this study, outward electrical opening, double-wing passenger door mechanical systems used in commercial vehicles were examined and various improvements were made. For the advantages of design changes; Road tests, bench tests, CAE analyzes, and torque-amperage measurements were performed. The results obtained from the tests were modeled in CAD environment, and CAE analysis was performed and compared with the results obtained from the tests

II. MATERIALS & METHODS

One of the important issues of public transport is timing. The most important factor in this timing is the time used in the landing-boarding of individuals. In order to optimize these landing-boarding times, the most important area to change vehicle systems is the design changes to be made to the doors. The design changes directly affect the landing and boarding times. As an improvement here, only the rapid opening and closing of the door should not be detected. The high speed of opening and closing will affect the drive systems negatively and will be the cause of ergonomic problems by the users. It will be injured in the field to be based on statistical measurements to be made in the field. Another suggestion for the changes in the mechanical systems of the doors is to provide in-car comfort. In order to prevent sound and air ingress, strictness must be taken for sealing, and some precautions should be taken. For this purpose, roving sections should be examined to increase the tightness and parts suitable to these sections, and standards should be used. Figure 1 shows the use of sample passenger doors in public transport.

Figure 1. Use of Sample Passenger Door in Public Transport Vehicles

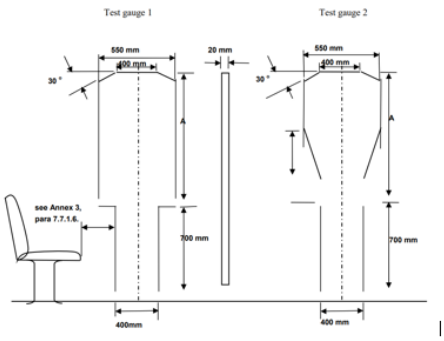
A. *General Information of Passenger Doors*

In a normal situation, passenger doors used for entrance and exit. Otherwise, in an emergency, they applied for passenger exit. Many different types of doors are used in the automotive sector. In the design of passenger doors and determination of mechanical systems; current controls and tests, compliance of international standards (eg. door opening measurement), checking compliance with demands from the sector, determining door opening-closing times, determining door usage quantities, determining door usage conditions.

The following factors are taken into account in the establishment of the test standards in accordance with the conditions and conditions of use:

- Design of Components Compatible with Test Standards
- Production Control
- Mentality Control
- Ergonomics and Packaging Control
- Numerical Analysis of the Elements
- Testing of the designed components on the test device
- Road Testing of the Designed Elements

Optimum values will be provided in the designs made according to these criteria. Design and manufacture of products as well as engineering standards, as well as an acceptable product in terms of the industry will be. The approval of the designed product by customers is a necessary parameter in the design of the products. In addition, in ECE R107-03 [21] standard, the opening values for the passenger doors are made through the test models. These test model values are shown in Figure 2.



Vehicle class	Height of the upper panel (mm) (Dimension "A" Figure 1)	
	Test gauge 1	Test gauge 2
Class A	950*	950
Class B	700*	950
Class I	1,100	1,100
Class II	950	1,100
Class III	850	1,100

* For vehicles of Class A or B, the lower panel may be displaced horizontally relative to the upper panel provided that it is in the same direction.

Figure 2. Passenger Door Clearance Dimensions [UN-ECE-R107-03]

B. *Electric Passenger Doors*

The electric passenger doors perform the opening/closing scenarios due to the transfer of the torque generated by the gearbox to the door wings by allowing the current to pass to the electric motors via the electrical module of the turn on/off switch used by the user.

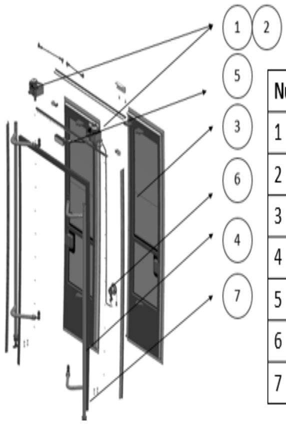
In accordance with the regulation, around the door; There are emergency exit handles inside and outside the vehicle. These levers generally enable the opening of the door by disabling the torques of the electric motors.

Especially in minibus type vehicles are very common. Among these reasons;

- Easy installation,

- Fast closing during the closing,
- Suitable for working in all weather conditions.

In addition to the operating characteristics of the passenger doors, sealing is also important. This can be achieved with wick choice and can also be validated by water/dust/road tests. When considering passenger comfort, sealing should not be ignored. The sub-systems of the electric passenger doors can be shown in Figure 3 [23].



Num	Components
1	Electric Motor
2	Gear Box
3	Door Wings
4	Handle Pipes
5	Inner Emergency Exit Handle
6	Outer Emergency Exit Handle
7	Sealings

Figure 3. Components of Electric Passenger Doors

The operation principle of the opening-closing movement for the electric passenger door is as follows. Electric motors are started to operate by the end of the module by the end-user by means of electrical signals. As a result of the torque production of electric motors, power is transferred to the door wing. As a result of all these operations, the passenger door can perform the opening-closing movement. Figure 4 shows the scenario of passenger opening and closing.

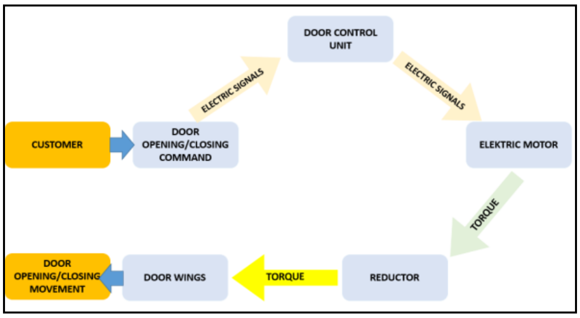


Figure 4. The scenario of Door Opening And Closing

C. Development Of Mechanical Systems Of Electric Passenger Doors

Improvements in the electric passenger gates were collected in two groups as mechanical and electronic.

Mechanical improvements,

- Measurement of the Mains of the Passenger Door Mounting Bracket and Improvements
- Measurement of Torque Values During the Operation of the Passenger Door
- Measurement of Torque Values (for every gear)
- Electric Motor Torque-Amper Measurement

Improvements made electronically,

- Creating Passenger Door Working Scenarios
- Creating appropriate algorithms for working scenarios
- Improvement of Soldering Quality on Electric Module
- Filtering of Parasites on Vehicle

has been determined. Mechanical improvements were examined in accordance with the thesis subject. No information was provided on electronic improvements.

1. Measurement of Passenger Door Mounting Bracket Deflection

It consists of the passenger door, wing group, reducer-motor group, and connecting brackets. The gear unit and motor assemblies belonging to the passenger door system are mounted on the mounting bracket, as can be seen in Figure 5.

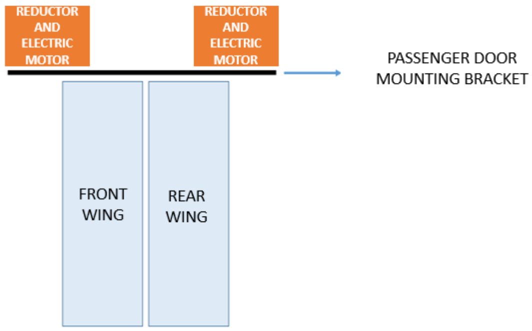


Figure 5. Passenger Door Assembly

High deflection of the passenger door mounting bracket will cause damage to the mechanical systems during operation. Deflection values were measured by CAE analysis. Figure 6 shows the improvements made to the mounting bracket.

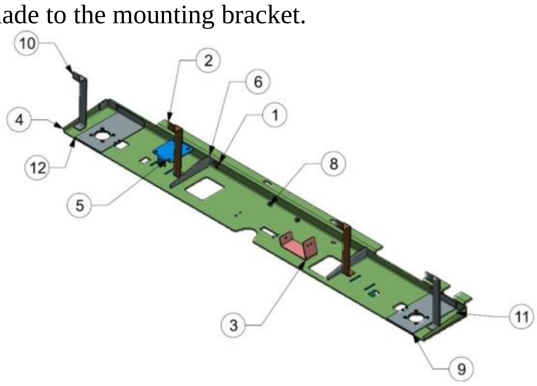
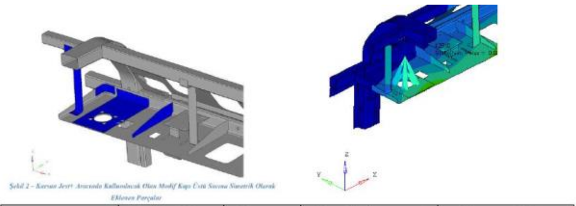


Figure 6. Improvements Of The Passenger Door Mounting Bracket

9,10,11,12 brackets have been added to improve the passenger door mounting bracket. After improvement work, CAE analysis was performed to see changes in deflection values. Von Misses stress values are used as a determining parameter in engineering studies. In Figure 7, the difference between deflection values is seen according to von Misses criteria.



	Engine Mass [kg]	Torque [Nm]	Max. Displacement [mm]	Max. von Mises Stress [MPa]
Nominal Tasarım	74	0	2.880	237.572
Modif Tasarım	74	0	0.609	104.146

Figure 7. Deflection Improvement of The Passenger Door Mounting Bracket

As a result of the improvements, a reduction in the amount of deflection was observed by 78%. This allows the gear unit and the motor assembly to operate

on a more rigid coupling bracket.

2. Measurement of Passenger Door Torque Values

The passenger door can be exposed to different torque values during difficult operation. During the determination of these values, torque measurements of the vehicle were made under the following conditions. Torque measurements are made under the following conditions. Figure 8 shows the slope values simulated in road tests.

A- Slope Road Tests

- Opening and closing of the door when braking
- Opening and closing of the door at the moment of acceleration

B- Uphill / Downhill Tests [on 110^0 Slope]

- Opening and closing of the door when braking
- Opening and closing of the door during acceleration

Figure 8. Road Tests Simulations

During the test, the Strain Gauge was connected to the door holding pipes, and the torque values were measured for the above conditions. In this system, since the holding pipes are connected to the gear unit and electric motor group, the torque values measured here are controlled by simulation, and their effects are examined. Figure 9 and Figure 10 show a torque and amperage measurement in certain conditions for the front and rear wing. The values are taken from a defined model.

Figure 9. Front Wing Torque-Current Measurement

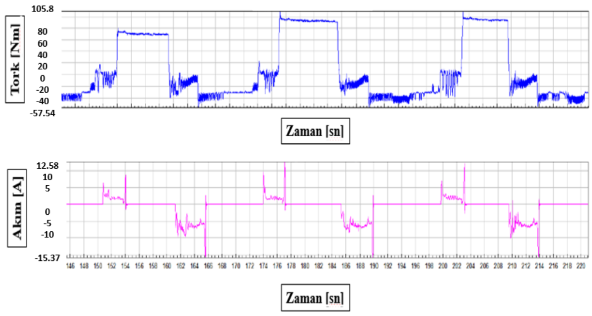


Figure 10. Rear Wing Torque-Current Measurement

As can be seen in Figure 10 for the front wing and for the rear wing, changes in the torque values are changed during the door-opening closure. These changes are used as input for design. Torque-Amper values vary according to the test conditions. It is the graph that has the highest values.

The highest values in these graphs are considered to be the worst-case in terms of simulation, and designs can be made accordingly.

3. Measurement of Gear Box Torque Values

Torque values measured by strain gauges connected to the passenger door holding pipes show the torque values that the gear 1 is subjected to. Based on this value, the torque values which were subjected to Gear 2, Gear 3, and Motor Motion Gear were calculated with the simulation made in ADAMS program. Figure 11 shows the gearbox schematic, and in this case, Figure 12 shows the torque values to which the gears are subjected under the conditions of Acceleration Instant Door Shutdown, Braking Instant Door Opening.

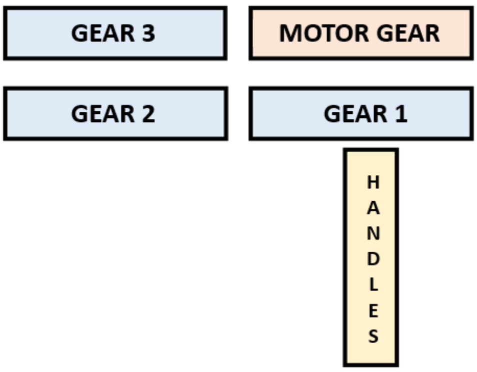


Figure 11. Gear Box Schematic

Hızlanma Anında Kapının Kapanması, Frenleme Anında Kapının Açılması								
Bölüm	Pik 1 (Nm)	Pik 2 (Nm)	Pik 3 (Nm)	Pik 4 (Nm)	Pik 5 (Nm)	Pik 6 (Nm)	Açılış Ort. (Nm)	Kapanış Ort. (Nm)
Tutunma Borusu	36,03	22,76	16,02	17,39	-20,39	-75,91	5,39	-9,91
Dişli 1	14,95	9,44	6,65	7,22	-8,46	-31,50	2,24	-4,11
Dişli 2	14,95	9,44	6,65	7,22	-8,46	-31,50	2,24	-4,11
Dişli 3	36,03	22,76	16,02	17,39	-20,39	-75,91	5,39	-9,91
Motor Dişlisi	2,99	1,89	1,33	1,44	-1,69	-6,30	0,45	-0,82

Figure 12. Acceleration, Door Closing, and Braking, Door Opening

In Figure 12, the peak values of the graphs shown in Figure 10 are read. These values were read when the car was in the downhill position; the door was closed at the moment of acceleration when the door was opened at the moment of braking. The most important factor in the selection of these positions and situations is the reading of the highest torque values on the passenger doors. Although different values are read in other cases, this situation is chosen by simulating the worst case, and choosing the material will be more accurate.

As can be seen in Figure 12, values of about handle pipes and gear-3 are 76 Nm, gear-1, and gear-2 are 76 Nm, and engine gear is 6 Nm were read at peak 6. For these torque values resulting from the measurements, a safety coefficient was determined, and the material selection of the gear group was completed. The main factor in determining the safety coefficients is the working conditions of the vehicle. According to these conditions, different safety coefficients can be selected, and no specific value is given in this section.

4. Measurement of Torque-Amper Values

Torque-current relations in electric motors are one of the motor characteristics that need to be examined. Depending on the operating conditions of the system, the amperage values change momentarily; they must change. Therefore, the torque values corresponding to the current values should be examined and a suitable electric motor is selected. For example, Figure 14 shows the power-ampere-cycle curves of the Kormas 631 034 58/5 603 067 120 001 motors [13]. As can be seen in Figure 13, measuring devices are available for torque-amperes, power-amperes-speed curves [24]. It is useful to perform measurements with these devices for control purposes.

Figure 13: E.D.C Torque-Current Measurement Device

The following values can be interpreted as a result of torque-current measurements.

- Maximum torque value of the electric motor
- Current values are taken by the electric motor
- Torque value of electrical motor with limiting current value

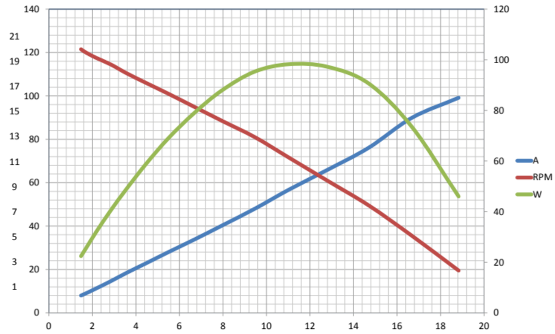


Figure 14: 631 034 58/5 603 067 120 001 Power/Current/Speed Curves

Each electric motor has an operating range specified by the manufacturer. The operation of electric motors from this driving range is not recommended. For this reason, the rated operating conditions of the selected electric motor must be checked and selected accordingly.

III. CONCLUSIONS

One of the main elements in public transportation vehicles used in the automotive sector is the passenger doors. In this study, outward electrical opening, double-wing passenger door mechanical systems used in commercial vehicles were examined, and various improvements were made. For the advantages of design changes; Road tests, bench tests, CAE analyzes, and torque-amperage measurements were performed. The results obtained from the tests were modeled in CAD environment, and CAE analysis was performed and compared with the results obtained from the tests. As a result of the tests carried out in the mechanical systems of the doors, it is seen that the examination of the following features is required in the design and improvement works.

- Electric Motor Selection
- Determining the Maximum Strength Conditions of Gears in Gear Boxes
- Ensuring the Rigidity of the Passenger Door Connection Bracket
- Providing Improvements with Path / Numerical Analysis
- Establishment of Validation Tests for Passenger Door Working Conditions

With the tests performed on mechanical systems, the following improvements have been achieved.

- As a result of the improvement in the passenger door mounting bracket, approximately 70% deflection was observed.

- As a result of this improvement, the operation of the passenger door has been made more rigid.
- In the gear unit and electric motor group, the working life of the machine group is extended under the maximum torque values of the electric motor or heavy operating conditions.
- Measuring the torque values of the passenger door during the operation made it easier to monitor and simulate vehicle operating conditions.
- According to these results, as a result of the torque values calculated for each gear, the safety coefficient was defined, and gear selections were made.

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