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STRENGTH DEVELOPMENT PROCESS OF WINDSHIELD WIPER SYSTEM COMPONENTS OF A BUS

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Abstract

Developing wiper systems is a crucial aspect of automotive engineering, particularly for ensuring visibility and safety during adverse weather conditions. While wiper systems for passenger vehicles are well-established, the unique demands of larger vehicles like buses present distinct challenges. These include needing longer wiper arms and more complex components to clear larger windshield areas efficiently. This study explores optimizing arm connection locations within bus wiper systems without altering existing components to improve system durability. A multi-body dynamics model is developed, and stress analyses are conducted on the wiper system's components under different torque conditions. The study focuses on optimizing connection points to enhance load distribution and reduce stress concentrations in critical areas. The results demonstrate significant improvements in system performance through optimized positioning, particularly in scenarios using motors with different torque values. The findings indicate that reconfiguring the connection points can reduce stress on critical components, thereby extending the system's lifespan. This approach offers a cost-effective solution for improving the durability and reliability of bus wiper systems, with potential implications for the design of future systems.

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BİR OTOBÜSÜN ÖN SİLECEK SİSTEMİ ELEMANLARININ DAYANIM OLARAK GELİŞTİRİLME SÜRECİ

Anahtar Kelimeler

Öz

Çoklu cisimler dinamiği,
sonlu elemanlar
metodu, silecek sistemi,
ticari araç

Silecek sistemlerinin geliştirilmesi, özellikle olumsuz hava koşullarında görünürlük ve güvenliği sağlamak için otomotiv mühendisliğinde önemli bir yere sahiptir. Binek araçlar için silecek sistemleri iyi kurulmuş olsa da otobüsler gibi daha büyük araçlarındaki farklı talepler bazı zorluklara neden olabilmektedir. Bunlar arasında daha büyük ön cam alanlarını verimli bir şekilde temizlemek için daha uzun silecek kollarına ve daha karmaşık bileşenlere ihtiyaç duyulması yer alır. Bu çalışma, sistem dayanıklılığını iyileştirmek için mevcut bileşenleri değiştirmeden otobüs silecek sistemlerindeki kol bağlantı yerlerinin optimize edilmesini içermektedir. Çoklu cisimler dinamiği modeli geliştirilip silecek sisteminin bileşenleri üzerinde farklı tork koşulları altında stres analizleri yapılmıştır. Çalışma, yük dağılımını iyileştirmek ve kritik alanlardaki stres konsantrasyonlarını azaltmak için bağlantı noktalarını optimize etmeye odaklanılmıştır. Sonuçlar, özellikle farklı tork değerlerine sahip motorların kullanıldığı senaryolarda, optimize edilmiş konumlandırma yoluyla sistem performansında önemli iyileştirmeler olduğunu göstermektedir. Bulgular, bağlantı noktalarının yeniden yapılandırılmasının kritik bileşenler üzerindeki stresi azaltabileceğini ve böylece sistemin ömrünü uzatabileceğini göstermektedir. Bu yaklaşım, gelecekteki sistemlerin tasarımı için potansiyel etkileri olan otobüs silecek sistemlerinin dayanıklılığını ve güvenilirliğini iyileştirmek için uygun maliyetli bir çözüm sunmaktadır.

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1. Introduction

Developing wiper systems is vital to automotive engineering, particularly in maintaining visibility and safety during adverse weather conditions. Clear vision and silent operation are usually dependent on the physical characteristics of the wiper, including the rubber of the blade, the material of the windshield, the friction between the blade tip and the windshield, the shape of the windshield curve, and the angle at which the blade attacks the screen (Zolfagharian, Noshadi, Zain and Bakar, 2013). While the design of wiper systems for passenger vehicles is well-established, the unique demands of larger vehicles, such as buses, introduce distinct challenges that require specialized solutions. The scale and configuration of buses necessitate wiper systems that are not only durable but also capable of efficiently clearing larger windshield areas (Zhang, 2010). This has led to longer wiper arms and a more complex array of components than those used in standard passenger cars. The ability to electronically manage the pneumatic wiping system on a bus has given the operator access to additional capabilities that help them comply with current and upcoming rules and requirements, in addition to the features deemed required to address such needs compared to older wiping systems (McIntyre and Frigon, 1995).

Issues such as the manufacturability of components, plant installation, simplification, appearance, cost, standardization, servicing, and compliance are of utmost importance throughout the design process (Cunningham, 1971). Studies have been carried out on more cost-effective and efficient systems using different types of controllers in the wiper motor (Joshi, Jogalekar, Sonawane, Sagare and Joshi, 2013). On another topic, unwanted noise is often caused by the reversal of a wiper; it is believed to be an impact sound that needs to be reduced for a comfortable ride (Sugita, Yabuno and Yanagisawa, 2012).

In bus wiper systems, this complexity is further intensified by the need to ensure uniform pressure distribution across the windshield, which is essential for achieving optimal wiping performance (Chevennement-Roux ve diğerleri, 2005). The increased length of the wiper arms and the larger surface area of the windshield require careful analysis of the mechanical and aerodynamic forces involved. Consequently, designing and optimizing these systems become a multifaceted challenge, requiring a delicate balance between component placement, arm length, and connection points.

Wiper systems, which have a vital importance in parallel with the development of technology, have been developed by many different organizations in terms of design and system from past to present (Kaur, 2022; Sharveswaran, 2020).

This study explores a novel approach to designing and optimizing arm connection locations within bus wiper systems. Unlike traditional methods that often involve

modifying components to meet performance goals, this research aims to enhance system efficiency without altering existing components. The objective is to reconfigure the arm connection points to maximize wiping coverage and consistency while preserving the system’s structural integrity and overall functionality.

By retaining the original components and concentrating on optimizing connection locations, this research seeks to provide a cost-effective and practical solution for improving the wiper system performance in buses. The outcomes of this study have significant implications for the design practices of bus wiper systems, offering insights that may lead to improved durability, and reliability in various operating conditions.

1.1 Windshield Wiper System

The visualization of the wiper system in the virtual environment is shown in Figure 1. In the specified model, the motor is not modeled directly but is provided to give direct input to the system. The system’s total weight, shown in Figure 1, is calculated as 9 kg. Connection types, materials used, and other parameters used in the system are discussed in the following sections.

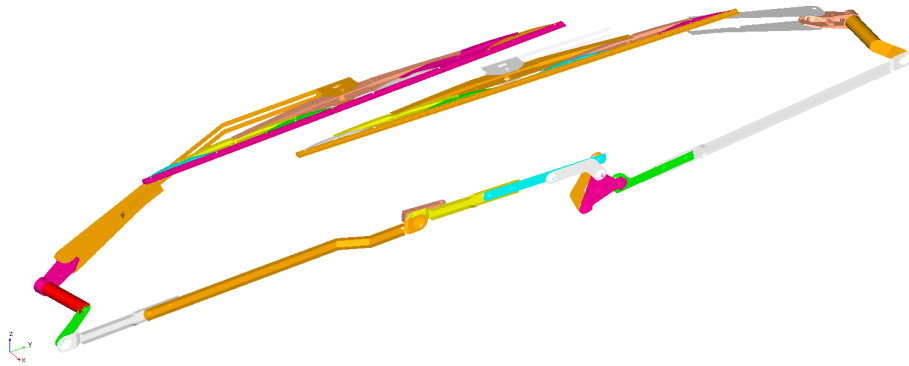


Figure 1. A Photo of the Wiper System

2. Analysis and System Information

This section focuses on multi-body dynamics modeling, designs, modeling of flexible structures, and inputs of analyses.

2.1 Multi-Body Dynamics Model

The numbering method is used since each part is to be evaluated in terms of stress. In this section, all connections and components are numbered, and all information is given according to these numbers.

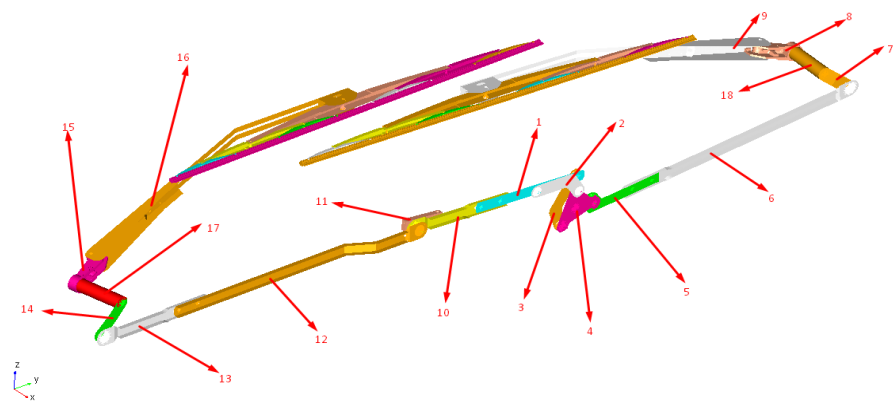


Figure 2. Numbering of Components (Existing Model)

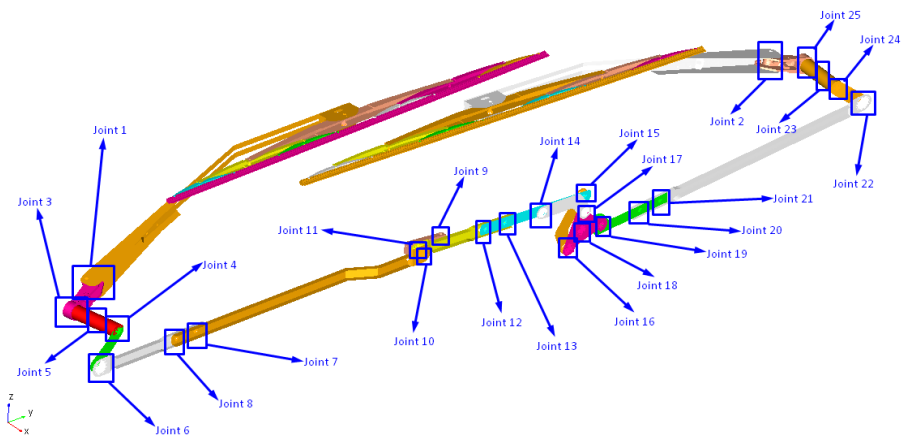


Figure 3. Numbering of Connections

Figures 2 and 3 show the numbering of the components and connections in the system. The connection types of these elements, which are essential for constructing the multibody dynamics model, are shown in Table 1.

Table 1. Connection Types and Included Components in the Model

Naming	Connection Type	Included Components
Joint 1	Revolute	15 and 16
Joint 2	Revolute	8 and 9
Joint 3	Revolute	15 and 17
Joint 4	Revolute	14 and 17
Joint 5	Fixed	17 and Ground
Joint 6	Spherical	13 and 14
Joint 7	Fixed	12 and 13
Joint 8	Fixed	12 and 13
Joint 9	Revolute	11 and Ground
Joint 10	Spherical	11 and 12
Joint 11	Spherical	10 and 11
Joint 12	Fixed	1 and 10
Joint 13	Fixed	1 and 10
Joint 14	Revolute	1 and 2
Joint 15	Revolute	1 and 3
Joint 16	Revolute	3 and 4
Joint 17	Revolute	2 and 4
Joint 18	Revolute	4 and Ground
Joint 19	Spherical	4 and 5
Joint 20	Fixed	5 and 6
Joint 21	Fixed	5 and 6
Joint 22	Spherical	6 and 7
Joint 23	Fixed	18 and Ground
Joint 24	Revolute	7 and 18
Joint 25	Revolute	8 and 18

Since the orientation of the links plays a critical role in the system’s operation, these values are assigned according to the “Euler Angles” method. Friction parameters are defined for the specified part connections. The static coefficient of friction between PTFE and steel material is analyzed as 0.15, and the dynamic coefficient of friction as 0.08 (The Engineering ToolBox, 2004).

2.2 Design Models

Since parts numbered 5, 6, 12, and 13 are essential load transfer components, updates are made by focusing on these parts in the new designs. Optimization work is done on the existing system, and the new design status is also examined. In the new design, parts 6 and 13 are shortened, while parts 5 and 12 are lengthened. The visual is as in Figure 4.

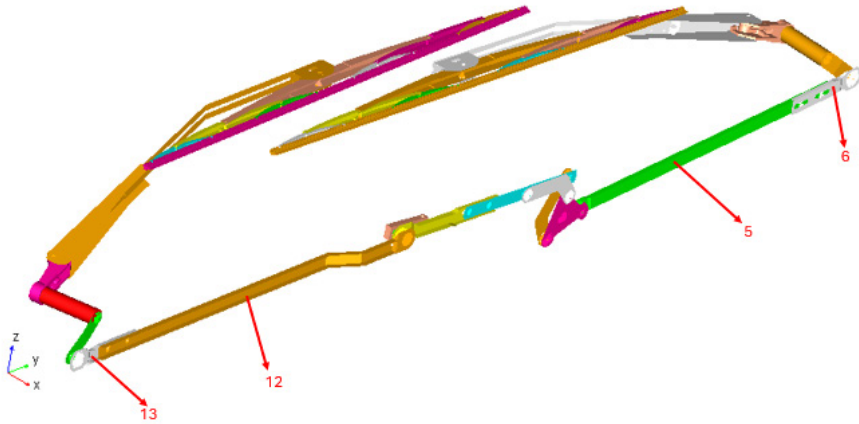


Figure 4. New Design Model

2.3 Finite Element Model

While creating the finite element model, yield strength, Poisson ratio, elasticity modulus, and density information of each part are entered, and analyses are made with linear models. The materials of the components used in the system are shown in Figure 5, and the material properties are shown in Table 2.

The wiper system operates in normal operation mechanism and analyzes are carried out in transient state.



Figure 5. Materials of the System

Table 2. Material Properties Used in the Flexible Model

Material	Yield Strength (MPa)	Poisson Ratio	Elastic Modulus (MPa)	Density (t/mm ³)
Steel 6112	280	0.3	210000	7.85E-09
Steel 6224	170-330	0.3	210000	7.85E-09
Steel 6222	170-360	0.3	210000	7.85E-09
St 37	235	0.3	210000	7.85E-09
SAE 1006	210	0.285	200000	7.87E-09
Zamak 5	269	0.25	87000	6.40E-09

2.4 Analysis Inputs

The input to the system is provided from the connection called Joint 9. In this system, where two different motors are used, the connection specified with the motor with a torque value of 80 Nm provides 264 degrees of rotation per second. The motor with a torque value of 120 Nm provides 300 degrees of rotation per second. It is possible to adjust the wiper system by changing the connection positions shown in blue in Figure 6. These connections are named Joint 8, 7, 12, 13, 20, and 21, respectively, from right to left. The constraints of the connections are determined according to the maximum distance they can move in the CAD model.

During the analysis, analyses are performed for two different motors with two different input values, and both design comparison and optimization studies are performed for both motor types.



Figure 6. Location Variables Used in Optimization

3. Results and Discussion

Throughout the study, in addition to making a comparison between the model used in existing vehicles and the new model, an optimization study is also con-

ducted to determine in which positions the models in existing vehicles should be used most appropriately.

3.1 Design Comparison

It can be observed that parts numbered 5, 6, 12, and 13 have changed between the models shown in Figures 2 and 4. While comparing the designs, no changes are made to the component numbers specified in Figure 2, and the comparison is made based on these numbers.

Table 3. Highest Von Mises Stress Values of Components using the motor with 80 Nm Torque

Com- ponent No.	Existing Model		New Model		New Model witho- ut Changing Com- ponents 5 and 6	
	Highest Von Mises Stress (MPa)	Angle of Input Compo- nent 11 (Degree)	Highest Von Mises Stress (MPa)	Angle of Input Compo- nent 11 (Degree)	Highest Von Mises Stress (MPa)	Angle of Input Compo- nent 11 (Deg- ree)
1	30.2	74.4	29.7	73.3	29.8	74.8
2	18.7	74.4	18.4	73.3	18.5	74.4
3	15.4	208.3	15.5	204.7	15.6	208.3
4	72.2	177.8	87.8	175.4	75.3	178.2
5	92.6	189.7	167.8	182.6	98.0	189.7
6	86.4	181.8	16.3	174.2	94.5	167.5
7	36.3	44.7	36.2	44.0	35.9	44.7
8	20.1	45.1	19.9	44.4	19.9	45.1
9	147.1	45.1	146.2	44.4	144.5	45.1
10	46.7	74.4	46.0	73.3	46.2	74.8
11	54.9	13.1	57.0	13.1	56.2	12.7
12	160.8	13.1	156.3	182.6	155.5	182.6
13	134.4	13.1	42.7	13.1	42.2	12.7
14	74.2	13.1	74.4	12.7	73.3	12.7
15	37.5	13.1	37.5	13.1	36.9	12.7
16	103.8	13.5	103.6	13.1	102.2	13.1

Table 4. Highest Von Mises Stress Values of Components using the motor with 120 Nm Torque

Com- po- nent No.	Existing Model		New Model		New Model without Changing Compo- nents 5 and 6	
	Highest Von Mises Stress (MPa)	Angle of Input Compo- nent 11 (Degree)	Highest Von Mises Stress (MPa)	Angle of Input Compo- nent 11 (Degree)	Highest Von Mises Stress (MPa)	Angle of Input Compo- nent 11 (Degree)
1	34.4	84.2	33.8	83.3	34.5	84.2
2	21.2	84.2	20.9	83.3	21.3	84.2
3	18.7	203.9	19.0	202.1	19.9	204.3
4	78.9	200.3	87.7	198.0	82.8	201.6
5	92.0	184.1	168.0	183.6	98.6	184.5
6	87.0	181.4	18.5	200.3	95.2	181.8
7	40.6	50.9	40.3	50.4	40.7	50.9
8	23.5	51.3	23.2	50.9	23.5	51.3
9	171.7	51.3	164.5	50.4	171.7	51.3
10	53.5	84.2	52.6	83.3	53.7	84.2
11	64.1	14.9	66.2	14.9	66.1	14.9
12	183.9	14.9	178.3	172.4	178.3	172.8
13	155.6	14.9	48.8	14.4	48.8	14.4
14	86.9	14.9	86.7	14.4	86.7	14.4
15	44.2	14.9	43.9	14.9	43.9	14.9
16	122.3	15.3	121.5	14.9	121.5	14.9

For both types of motors, the stress values of the motor system with 80 Nm torque are found to be lower. It can be deduced that the system with an 80 Nm motor will have a longer lifespan. The stress values are 10% lower on average for the motor system with 80 Nm torque than the new and existing designs. When the new design and existing design results are compared, a 68% decrease in one of the stress values of the arms on the left side (parts 12 and 13) of the mechanism

and a 3% decrease in the other are observed. On the right side of the system (parts 5 and 6), an 80% increase in the stress values of the newly added long arm is observed, while an 80% decrease in the stress values of the short arm is observed. As a result of the analyses, in the case of changes only to the left mechanism, a 68% decrease in one of the stress values of the arms on the left side of the mechanism and a 3% decrease in the other are observed, while the increase on the right side is determined to be an average of 7%. Considering the highest stress values, changing only the arms on the left mechanism would be appropriate.

An example image of the wiper system being fully opened during the analysis is shown in Figure 7.



Figure 7. Fully Opened Wiper System During an Analysis

3.2 Optimization Results of the Existing Model

According to the analysis results, the parts with the highest stresses are numbered 9, 12, 13, and 16. In addition, an increase in stress values is observed when the motor with a torque value of 120 Nm is used. It is anticipated that this situation will negatively affect the system's strength.

The movement of 3 parts determines optimization inputs. Analyses are made according to the new order formed due to the movements of these parts. The stress values are examined due to changing the positions of 6 connections, such as joints 8, 7, 12, 13, 20, and 21. In addition to trying to reduce the stress values, the connection positions with high resultant force are also examined. In light of these parameters, it is aimed to determine the appropriate positions. In the optimization studies, the positions of the changed joints 7 and 8 are called the left position, joints 12 and 13 are called the mid position, and joints 20 and 21 are called the right position.

The studies determine three suitable positions for systems with motors producing 80 and 120 Nm torque. While making improvements, these values are evaluated by comparing them with the existing system positions.

Table 5. Optimum Locations for the Motor with 80 Nm Torque in the Existing System

Locations	Distance Information (mm)		
	Scenario 1	Scenario 2	Scenario 3
Left Position	-10	-2	-10
Right Position	6	7	3
Mid Position	13	15	-10

Table 6. Results According to Scenarios for 80 Nm Torque Motor

Component No.	Highest Von Mises Stress Value (MPa)			
	Scenario 1	Scenario 2	Scenario 3	Existing Model
9	133.3 (%9.4)	98.8 (%32.8)	147.5 (%-0.3)	147.1
12	138.5 (%13.9)	154.4 (%4.0)	136.2 (%15.3)	160.8
13	132.5 (%1.4)	133.8 (%0.4)	132.8 (%1.2)	134.4
16	102.0 (%1.6)	102.9 (%0.8)	102.7 (%1.0)	103.8

The scenarios shown in Table 6 are the results obtained according to the positions specified in Table 5. It can be seen that the stress values are reduced by making only position adjustments without making any part changes. The results obtained in Scenario 1 show the optimum results and are selected because the average decrease in the stresses of the components is at the best level. In Scenario 2, significant decreases are observed in the stress value of component number 9, and this is a scenario that can be selected in case of a problem on this component. In Scenario 3, the most significant development is in component number 12, the least recommended option among these three options.

Table 7. Optimum Locations for the Motor with 120 Nm Torque in the Existing System

Locations	Distance Information (mm)		
	Scenario 1	Scenario 2	Scenario 3
Left Position	-10	-10	-10
Right Position	2	7	5
Mid Position	6	15	-10

Table 8. Results According to Scenarios for 120 Nm Torque Motor

Component No.	Highest Von Mises Stress Value (MPa)			
	Scenario 1	Scenario 2	Scenario 3	Existing Model
9	72.9 (%57.5)	89.8 (%47.7)	95.4 (%44.4)	171.7
12	156.7 (%14.8)	157.2 (%14.5)	156.5 (%14.9)	183.9
13	154.6 (%0.6)	153.3 (%1.5)	154.8 (%0.5)	155.6
16	121.8 (%0.4)	120.9 (%1.1)	121.9 (%0.3)	122.3

The scenarios shown in Table 8 are the results obtained according to the positions specified in Table 7. It can be observed that the stress values decrease with the 120 Nm torque motor by making only position adjustments without changing the parts. The results obtained in scenario 1 are the most recommended, and significant decreases were obtained, especially in the stress values of component number 9. In addition, significant decreases can be observed in component number 12. Similar results are obtained in all three scenarios, and the component-based stress decreases are at similar levels. In addition, since the position selections of scenario 1 of the 80 Nm torque motor and scenario 2 of the 120 Nm torque motor are similar, they include results that can be used together.

When the analyses made with the 80 Nm torque motor are compared with those made with the 120 Nm torque motor, increases in stress values are observed along with increases in the torque value of the motor.

In this study, research and publication ethics are followed.

4. Conclusion and Future Work

Due to the long arms in the bus wiper systems, making adjustments suitable is a situation that allows development in terms of strength. Thus, it is possible to see the positive effects on resistance by providing load distribution on two arms instead of a single arm. It also allows such studies to be carried out to bring better endurance levels to the vehicles currently in use. Apart from this, developing a new design can be a more practical application for the vehicles to be newly implemented. At this stage, the primary goal should be to determine the improvement status of the system's resistance. Thus, after the system's suitability is determined with the relevant studies, applying more accurate positions with position adjustments could be a suitable process for improving the endurance of the wiper system.

In this study, studies are carried out to extend the life of the wiper system and it is emphasized by other studies that frictional noises consist of 3 categories: the squeal, chattering and reverse noises (Wang, 2023). Studies can be carried out to reduce frictional noise.

In further studies, modeling the contact between the wiper and the glass and the resistances in the rubber part according to this modeling can be examined. In addition, examining the resistance of the wiper system connected to the vehicle and the inputs coming from the road and the air allows for a more comprehensive study.

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