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Dynamic modeling and simulation of windshield wiper mechanism

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Abstract
The large windshield glass surface of the automotive requires to be cleaned for a good visibility. The wiper arm mechanism driven by an electric motor is well adopted to clean the large surface area of the windshield. Most of the Wiper mechanisms adopts the simple four bar mechanism or parallelogram mechanism for the working which works by transmitting the power from an electric motor to the roots of wiper arms converting rotary motion into back and forth motion. The present work attempts to simulate and analyze the dynamic behavior of a wiper tandem mechanism by using the software packages, CATIA V5R20 for modeling; ANSYS for analysis considering the mechanism as multibody system. The paper also presents the distribution of equivalent stress in the coupling linkages and joints of the mechanism to predict the probable area of failure.

Keywords: Rigid dynamics, Wiper mechanism, Multibody system, Linkages, Stress

Introduction
The wiper mechanism was developed to clean the water or dust from the windshield glass of an automobile. The widely adopted wiper mechanism systems includes tandem system, opposed system, single arm system and driver position system. Figure 2 illustrates the tandem wiper mechanism which operates on the parallelogram principle consisting two wipers; one is used to clean the windshield glass at the driver's side while the another to clean the passenger's side. The back and forth motion of the wiper is usually operated by an electric motor. The mechanism mainly comprises the driving unit that is an electric geared motor, the linkage mechanism, wiper arms and the rubber blades. An electric motor is provided with worm gear reduction which reduces the speed of the motor with considerable increase in the driving torque. The speed reduction gear produces an enough driving torque to operate the wiper arms. The output shaft of the motor is coupled with the drive link which further drives the coupler connecting links, converting the rotational motion into translational. The force from the motor to the coupler link turns the wiper arms through the pivots. The rubber blades are held by the wiper through number of pressure points also called as "claws", the claws ensure the uniform pressure distribution on the windshield glass along the total length of the blade which ensures the friction between the rubber and the glass. The wiper can rotate about the pivot and the spring mechanism between the pivot and the drive link brings the wiper arm to rest close near to the windshield. The whole assembly of motor, crank (drive link), coupler link and the pivots are made rigidly fixed underneath of the dashboard.
Some manufacturers produce two different assemblies of the wiper and the wiper mechanism while some make a complete assembly of both along with the motor. The whole assembly comprising different parts are made up of different materials. The crank (drive link) and the coupler linkages are made up of steel coated with zinc called as Galvanized steel; the coating of zinc protects the steel from corrosion. The pivot transmitting force form linkage mechanism to the wiper arm are also made up of Galvanized steel. The wiper arm is manufactured from Aluminum alloy and the rubber is made up of natural rubber which is quite soft at the wiping edge and hard at rest of the holding portion. The other parts including springs, nuts, bolts and the supporting bracket is made up of steel and are directly purchased from the specialized companies. Copilusi Cristian and Veliscu Viorica [1], "An Approach Regarding Windshield Wiper Mechanism Design" have presented a computer oriented numerical approach of parallelogram mechanism used in automobile windscreen wiper system and evaluated the frictional force between the rubber blades and the windscreen glass.

Another research article C Alexandru [2], "Aspects regarding the wiper windshield mechanism analysis by considering as multibody systems" also analyzed the parallelogram mechanism and determined the reaction forces and moment of inertia, also the mathematical model is solved to obtain the actuation torque. Harun Gökçe and İsmail Şahin [3] "Design and Kinematic Analysis of Windshield Wiper Mechanism Using CATIA V5" have simulate a CAD model of wiper mechanism and proposed an accurate path of the mechanism also the velocity and acceleration analysis is performed for the motor input.

The present work attempts to simulate the dynamic behavior of a tandem wiper mechanism using Finite element method. The geometric model of the wiper mechanism was built in a three-dimensional software, CATIA V5R20 and the dynamic simulation was performed in ANSYS 18.1.

1. Kinematics of Wiper mechanism

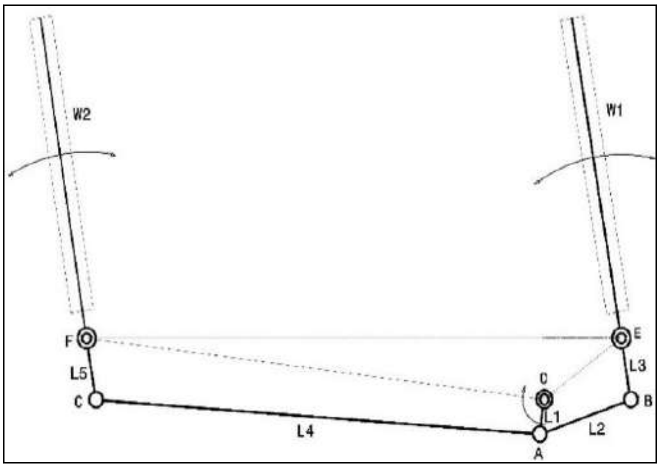


Fig 1: Kinematic model of wiper mechanism

Figure 1 elaborates the schematic representation of the tandem system. The mechanism contains two four-bar mechanisms, the primary mechanism O-A-B-E transmits the working force to right wiper W1 at the driver's side while the secondary mechanism O-A-C-F operates the left wiper W2 at the passenger's side. The linkage L1 represents the driver link (crank) coupled to the output shaft of the motor at point O. The drive link L1 and both the wiper links (L3 & L5) are connected to the car body through revolute joints O, E and F respectively. The force is transmitted to the wiper arms from the motor crank via the two coupler arms L2 and L4 connected through spherical joints B, C and a common cylindrical joint A. Thus, the wiping motion is transmitted from an electric motor to the shafts of the wiper arm via the assemblies of crank, coupler linkages and the joints. The degree of mobility of the mechanism can be calculated by Gruebler's equation, DOF=3(n-1)-2L-H where, n is the total number of mobile links in the mechanism; L is the total number of lower links including sliding joints and pin joints; H is the number of higher pairs such as gear joints and cam which usually have 2 DOF. Here, the mechanism comprises 2 pin joints; 2 spherical joints and one common cylindrical joint hence, the mechanism under study has 1 degree of freedom.

2. How to generate Finite-element-model of Wiper mechanism

The ANSYS's Rigid Dynamics module formulates and solve the kinematic equations of motion of each rigid part of the mechanism. The connections and type of contacts between each part of the mechanism were defined to corelate the relation between the structure parts. The analysis includes dividing the analysis process into number of steps or the step is further divided into sub steps according to the type of analysis. The kinematic behavior of the mechanism is further determined by evaluation performed in the next step of post-processing of results. The post-processing of the results involves drawing the kinematic quantities including velocity, displacement, position and velocity. The results also provide the virtual graphic animation of each quantity and the result report.

The CAD model of the wiper mechanism is generated in the CATIA V5R20 and the CAD-file of the mechanism can be imported in A Rigid Dynamics module using the IGES interface. The material is assigned to each part of the mechanism through the engineering material library. The physical and mechanical properties of the assigned materials are given in table 1. The forces in the linkages primarily acts in the axial direction and causes very less deflection hence for the present dynamic simulation, the linkage members are taken as rigid bodies [1]. The wiper mechanism model is shown in figure 2.

Table 1: Material properties of parts of mechanism

Material	Density (Kg/m3)	Young's Modulus (GPa)	Poisson Ratio
Steel	7680	200	0.3
Aluminum Alloy	2710	69	0.32
Rubber	1522	0.001	0.4999
Glass	2560	50	0.25

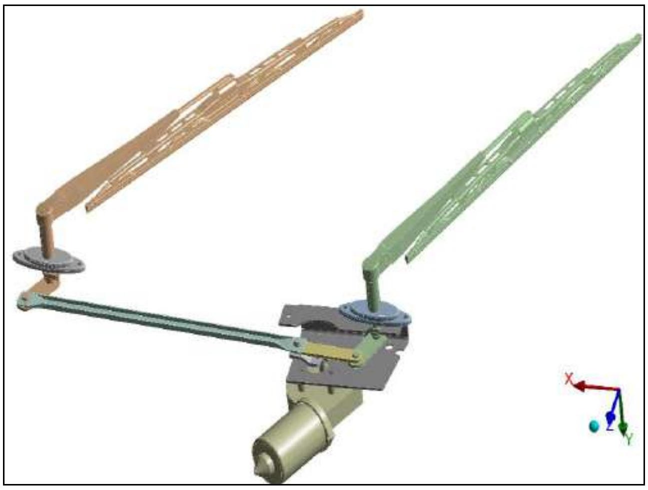
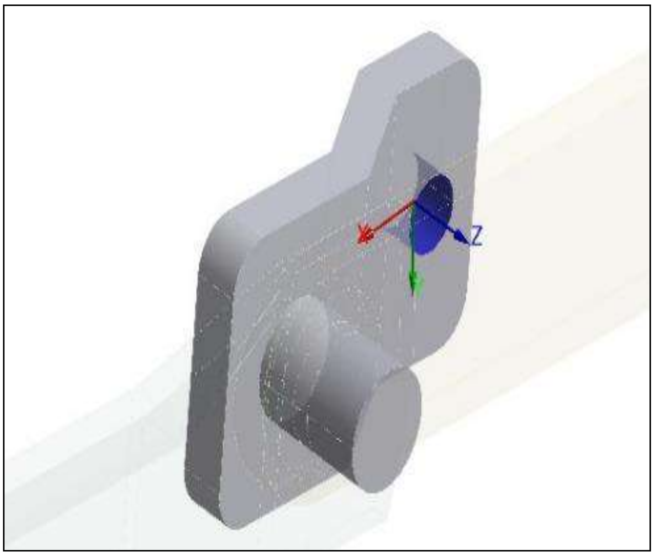


Fig 2: Windshield tandem wiper mechanism

The mobility of all the rigid parts of the mechanism was restricted through the geometric constrains and the other parameters such as joints that defines the location. The connections are defined between the rigid parts to establish constraints to the mechanism as shown in figure 3(a) which illustrates the constrains, the joints provided for the mechanism. The drive crank is coupled with the shaft, hence rotate joint was provided with respect to ground as shown in figure 3(b). The revolute joint was assigned between both the coupler links and the crank whereas a rotating joint was provided between the pivots of the wiper arms and the holding clamp underneath the dashboard. The other rigid parts including motor, bracket and the holding clamps were kept fixed in the coordinate system. An automatic free mesh is generated which discretize the geometry in number of elements for numbers of numerical simulations. The driving torque is transferred from the motor shaft to the mechanism, rotating at the speed of 35 rpm that is at the rate of 3.665 radians per second. The rotational velocity of 3.665 rad/sec is provided at the rotational joint at the crank and shaft joint. The claws provided at the wiper arm ensures the uniform distribution of the pressure on the windshield along the length of the blade ensuring the friction between the glass and the rubber. The friction between the rubber and the glass should not considered constant because with the change in the direction of motion of the arm, the friction will also be varying but for the analysis purpose it was considered to be 0.2. The external load was applied on the wiper arm consist of pressure force on the windshield wiper blade on the windscreen surface. Also, another analysis was carried out in Transient analysis module to determine the maximum and minimum von-Misses stress distribution and to the figure out highly stressed region in the mechanism.

(A)

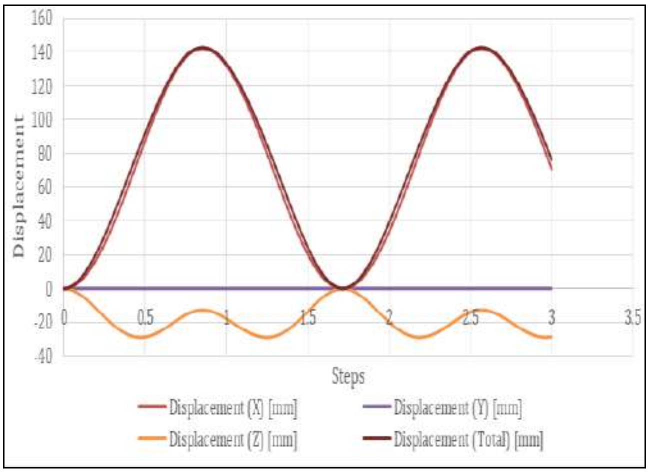


(B)

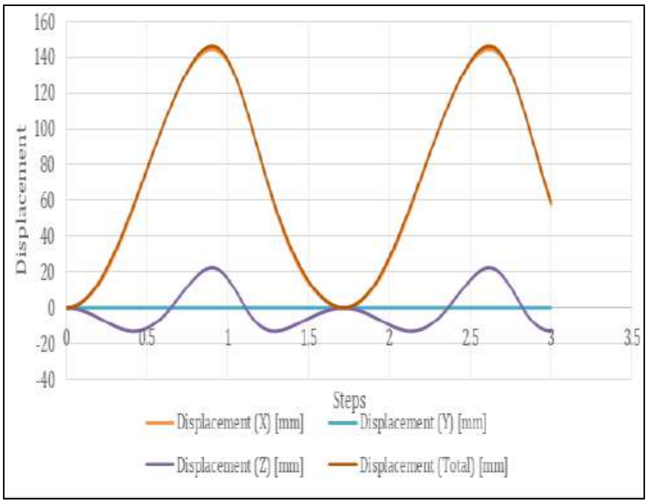
Fig 3: (a) Kinematic joints and constraints, (b) Defining the rotating velocity to the driving crank

3. Results and Discussion

Design study represents a set of simulations which helps to obtain the results in table or graphical form of various quantities. Depending upon the constrains applied, the simulation was carried out for 3 steps to obtain the travel of the wiper arm and the results correspond for two complete rotations of the motor crank. Figure 4 shows the graphical displacement of both the wiper arm over the windshield glass; fig 4(a) and 4(b) shows the graphical representation of wiper at the driver's side and passenger's side.



(A)

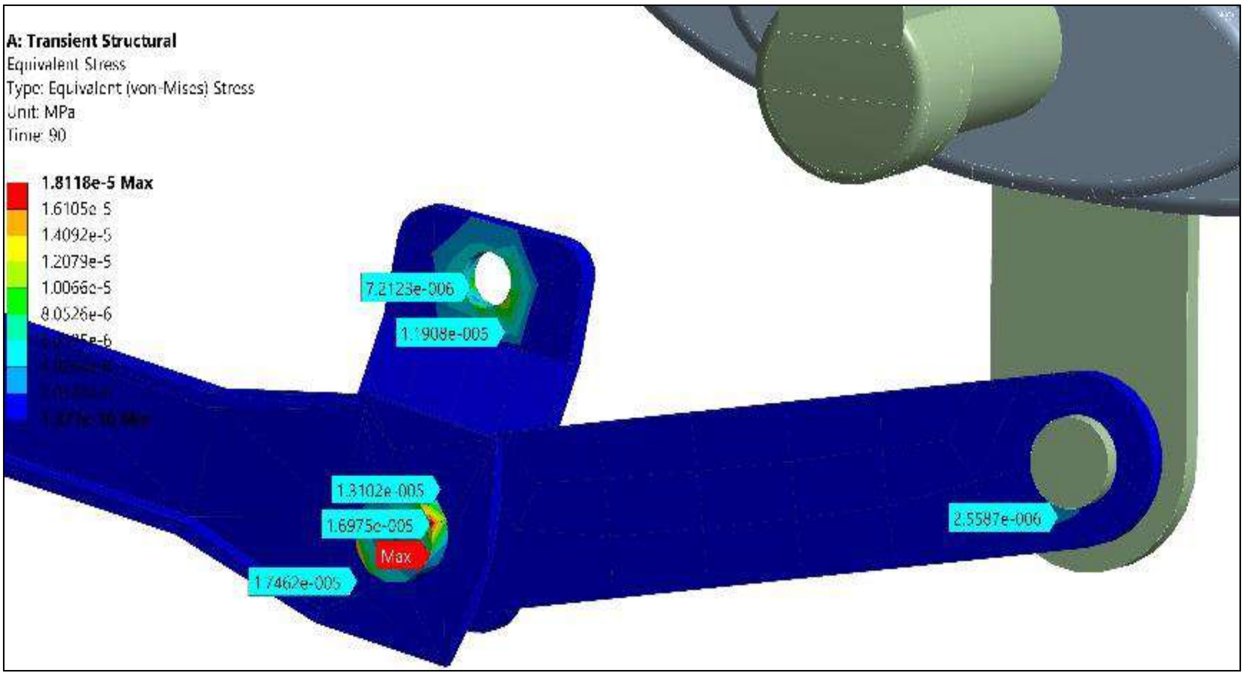


(B)

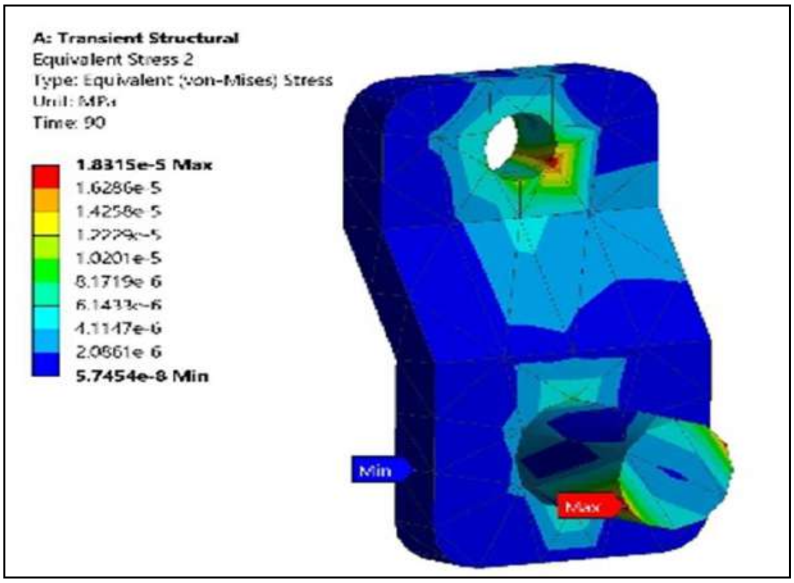
Fig 4: Total displacement of wiper at (a) driver's side and (b) passenger's side.

Graph shows the arm travel in X, Y and Z direction represented by different color codes in which the displacement of the wiper arm in X, Y and Z direction defines the point of moving part and it traces the path of each wiper arm over the glass shield. This overviews the windshield glass area wiped by the wiper arm can be obtained by the travel of wiper in three axes specifying the accurate path of the mechanism.

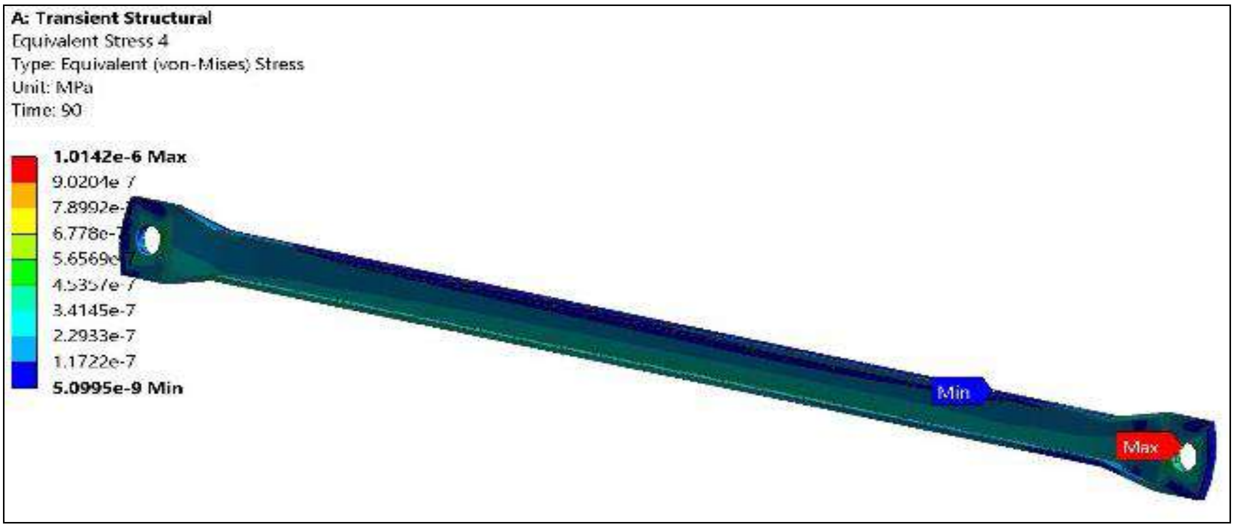
Afterwards, the model was analyzed to determine the stress distribution. The wiper arms are subjected to minimal stress and hence keeping both wiper arms as rigid body and crank, the two coupler arms as flexible bodies, the same joints connections and the boundary conditions are applied same as dynamic simulation. The simulation one complete rotation of the crank divided into 90 steps.


A: Transient Structural
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 90
1.8118e-5 Max
1.6105e-5
1.4092e-5
1.2079e-5
1.0066e-5
8.0526e-6
7.2123e-006
1.1908e-005
1.3102e-005
1.6975e-005
Max
1.7462e-005
2.5587e-006

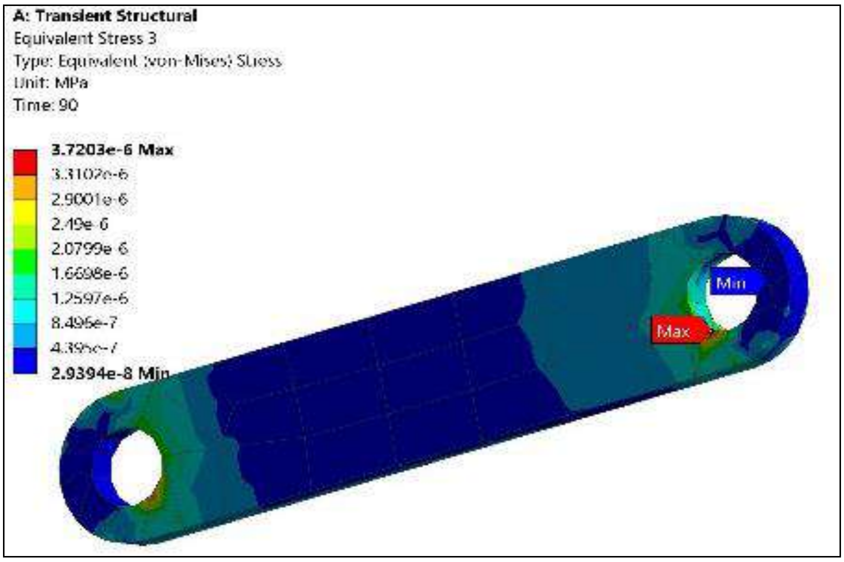
(A)


A: Transient Structural
Equivalent Stress 2
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 90
1.8315e-5 Max
1.6286e-5
1.4258e-5
1.2229e-5
1.0201e-5
8.1719e-6
6.1433e-6
4.1147e-6
2.0861e-6
5.7454e-8 Min
Min
Max

(B)


A: Transient Structural
Equivalent Stress 4
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 90
1.0142e-6 Max
9.0204e-7
3.4145e-7
2.2933e-7
1.1722e-7
5.0995e-9 Min
Min
Max

(C)



(D)

Fig 5: Maximum Equivalent stress induced in (a) Wiper mechanism, (b) Drive crank, (c) Coupling linkage L4, (d) Coupling linkage L2.

According to the graphics from figure 5(a), the maximum von-Mises stresses were acting at the joint between the crank L1 and the coupler arms L2 and L4 hence the probability of failure of mechanism is maximum at the crank joint A. The probe was used to obtained the resulting equivalent von-Mises stress at different locations of the mechanism. Figure 6 shows the graphical representation of the stress behavior of the mechanism during one complete cycle. Also, the equivalent stress induced in the crank, both the coupler links are illustrated in the figure 5(b), 5(c) and 5(d) respectively. The longer coupler link transmitting the force from crank to passenger's side wiper arm is subjected to maximum equivalent stress amounting 1.0142e-06Mpa, while the shorter coupler arm transmitting the working force from crank to driver's side wiper arm is subjected to maximum equivalent stress of 3.7203e-06Mpa. According to the graphics from the figure 5(a), the stress distribution in the driving crank indicates maximum stress is induced at the joint 'A' connecting the crank to both the coupler arms which is equivalent to 1.8315e-05MPa indicating the probable point of failure in the mechanism.

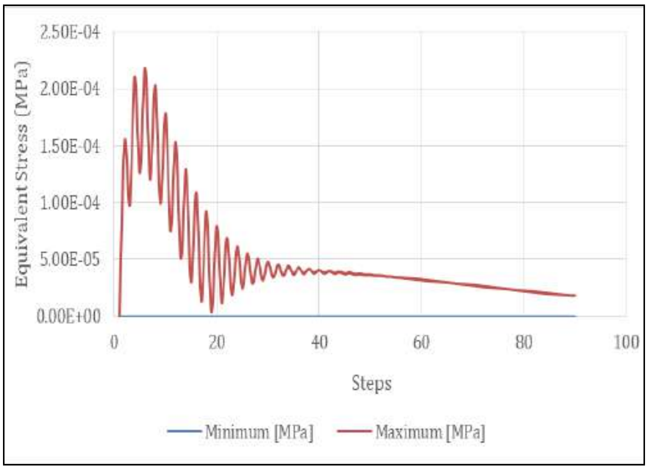


Fig 6: Stress behaviour in wiper mechanism

4. Conclusions

For a tandem windshield wiper mechanism considered as multibody system was simulated to obtain the kinematic and kinetostatic quantities such as displacement, angular acceleration and position of the wipers. The displacement of the wiper arm in X, Y and Z direction defines the point of the moving part and hence traces the path of each wiper arm over the glass shield, in general it gives the overview of the area of glass wiped by the wiper arm. Also, the stress behavior of the mechanism was analyzed to obtain highly stressed region and from the results obtained, the joint between the motor crank and the two-coupler links experiences the maximum equivalent force under the working conditions. Hence, the probability of failure is more at the joint between crank and coupler links.

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