Design and Validation of DC Geared Rack-Pinion Wiper Motor for Passenger Vehicles (Car/Rickshaw)

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Abstract: *The paper presents the experimental validation of an electrochemical based rain sensing wiper system which operates a DC geared motor connected to the wiper of an automobile. The DC geared motor is available off the shelf and will lead to 18% reduction in torque required, 60% weight reduction, 1/3rd original size and 50% of overall cost of the wiper system. However, there is a significant increase of 30 % in current drawn with the newly proposed system and hence a reduction in battery life of 24%. The DC geared wiper system is available in India and works with the rack and pinion arrangement which will transmit the necessary torque to the wiper, both for the autorickshaw and the conventional passenger vehicle.*

Keywords – *DC geared motor, wiper motor, electrochemical, rain sensing, torque reduction*

INTRODUCTION

Due to heavy rains lot of vehicles lose their electronic capability due to water logging which can result in loss of life of individuals. A rain sensing wiper and alert system [1],[2],[3],[4] that works on a principle other than electronics and independent of the micro controller [7] of the vehicle would be a boon in such a situation. The voltage can be made to close the windows or open the door locks/windows during heavy rain allowing passengers to escape from the vehicles. A low-cost automatic rain sensing wiper will be extremely useful in such a scenario.

Section 2 discusses about literature review. Section 3 discusses the mathematical design of the conventional Lucas wiper motor and electrochemical rain sensor (ERS), and the various parameters associated with its sensitivity are discussed in detail. It presents the detailed mathematical model for the newly proposed DC geared motor with the rack and pinion arrangement. Section 4 presents the comparison of the DC geared wiper motor system with the conventional Lucas wiper system. Section 5 presents the experimental validation of the proposed system as done during lockdown conditions. Section 6 discusses the salient features, conclusions, and future work.

Figure 1: - Electrochemical Rain Sensing (ERS) DC geared Wiper system

LITERATURE REVIEW

In the past, automakers have tried to either eliminate the wipers or to control their speed automatically. Some of the schemes involved detecting the vibrations caused by individual raindrops hitting the windshield, applying special coatings that did not allow drops to form, or even ultrasonically vibrating the windshield to break up the droplets so they don't

need to be wiped at all. But these systems were plagued by problems and either never made it to production or were quickly axed because they annoyed more drivers than they pleased.

However, a new type of wiper system is starting to appear on cars that do a good job of detecting the amount of water on the windshield and controlling the wipers. One such system is made by TRW Inc. [6] uses optical sensors to detect the moisture. The sensor is mounted in contact with the inside of the windshield, near the rear-view mirror.

The sensor projects infrared light into the windshield at a 45-degree angle. If the glass is dry, most of this light is reflected into the sensor by the front of the windshield. If water droplets are on the glass, they reflect the light in different directions -- the wetter the glass, the less light makes it back into the sensor.

The electronics and software in the sensor turn on the wipers when the amount of light reflected onto the sensor decreases to a present level. The software sets the speed of the wipers based on how fast the moisture builds up between wipes. It can operate the wipers at any speed. The system adjusts the speed as often as necessary to match with the rate of moisture accumulation.

MATHEMATICAL MODEL

The mathematical models of both the systems are presented in this section

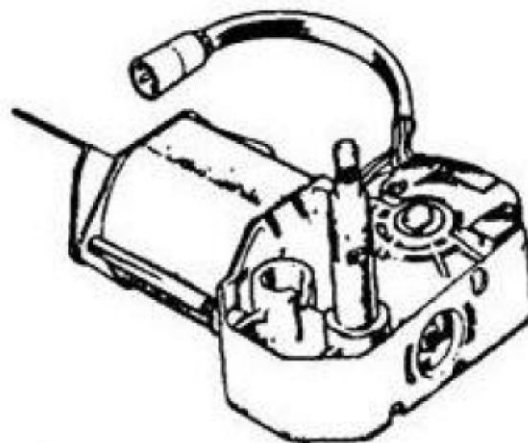A - Conventional Lucas Wiper Motor System [8]

Figure 2 – Conventional Lucas Wiper Arrangement for Single wiper

The conventional Lucas motor consists of worm and worm wheel attached to a DC motor and operating a four-bar mechanism to rotate the wiper. The equation of torque produced by the Lucas motor is shown below

$$T = F\ \mu\ f_s\ f_l\ l\ (\omega_a/\omega_m)(R_h/R_c)(1/e)$$

where:

T = torque to move one wiper arm (N-m)

F = force onto blade on screen (N) = (W + 0.8) cos (β + λ)

W = 250 gms weight

Frictional force, 0.8 N = maximum frictional force on blade [5]

β = angle of travel by wiper (rad) = max 180 – 2λ

λ = relief angle on windscreen = 15-degree

μ = maximum dry coefficient of friction, which is 2.5

f_s = multiplier for joint friction, which is 1.15

f_l = tolerance factor, which is 1.12

l = wiper arm length, m which is 0.4 m

ω_a = maximum angular velocity of arm, rad/s

ω_m = mean angular velocity of motor crank, rad/s

e = efficiency of motor gear unit which is 0.8

R_h = motor winding resistance, hot-Ω = 1.05

R_c = motor winding resistance, cold-Ω = 1

Figure 3 – Various parts of the conventional wiper assembly

B - DC Geared Motor Rack and Pinion Wiper System [8]

Taking downward direction as positive

$$W + mg = N \ldots\ldots\ldots\ldots(1)$$

Taking right side positive

$$-F_t + \mu N = -m\ddot{x} \ldots\ldots\ldots\ldots(2)$$

Moment about O taking clockwise positive

$$-T - WL\cos(\beta + \lambda_0)/2 + F_t R - \mu NR = I\ddot{\beta} = (WL^2/3g)\ddot{\beta} \ldots\ldots\ldots\ldots(3)$$
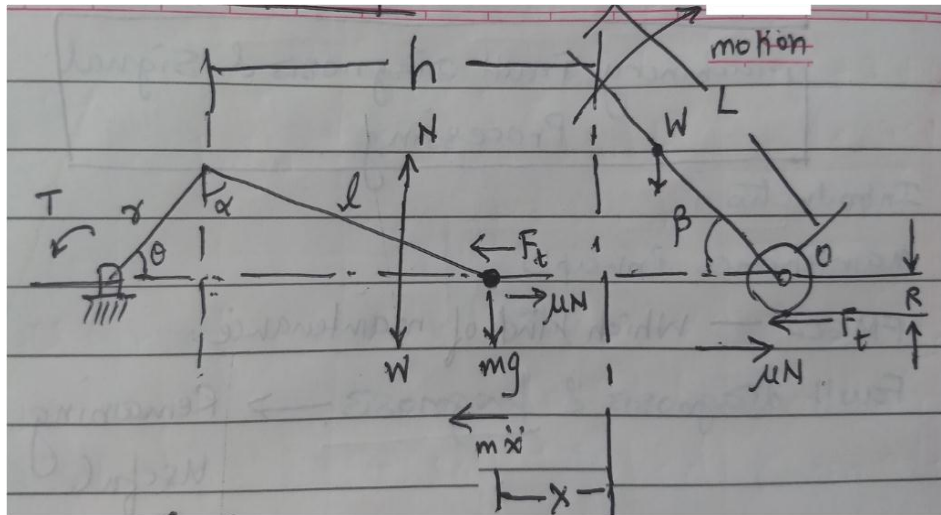
Figure 4 – Free Body Diagram of the ERS based wiper system

Also, for the pinion and rack arrangement,

$\beta = -x/R$

$\dot{\beta} = + \dot{x}/R$

$\ddot{\beta} = -\ddot{x}/R$

Substituting in the equation (3), we get

$$T = [(WL^2/3gR) + mR]\ddot{x} - (WL/2)\cos(\beta + \lambda_0) \quad \text{................................(4)}$$

Consider the rack and pinion configuration as shown in Figure below. In a pinion rotation of $180 - 2\lambda_0$ deg in a single direction, the rack covers distance equal to ONE travel length. The relief angle on the windshield is given by $\lambda_0 = (2\pi - 2(x_m/R))/4$.

COMPARISON OF PERFORMANCE OF WIPER SYSTEMS FOR AUTOMOBILE (RICKSHAW)

The validation of the ERS DC geared wiper system was carried out on the windshield wipers of a rickshaw. Similar analysis was carried out on the wiper blade for a compact car or sedan. Details of the parameters of the wiper blades, conventional wiper motors and DC geared wiper motor is as shown in Table below.

Table 1: Conventional Lucas motor wiper system and DC geared motor wiper system

Case A – Autorickshaw				Case B - Compact car / Sedan			
Wiper parameters	Conventional wiper motor		DC geared motor [9]		Wiper parameters	Conventional wiper motor		DC geared motor [9]	
Weight	60 RPM	No load current	60 RPM	No load current	Weight	60 RPM	No load current	60 RPM	No load current
0.25 kg	12 V	1.4 A	12 V	0.3 A	0.33 kg	12 V	1.4 A	12 V	0.8 A
Length	Weight	Max current	Weight	Max current	Length	Weight	Max current	Weight	Max current
0.4 m	800 gm	14 A	180 gm	7.5 A	0.55 m	800 gm	14 A	300 gm	7.5 A
Make	Holding Torque	Make	Holding Torque	Make	Make	Holding Torque	Make	Holding Torque	Make
BOSCH	18 N-m	DENSOIndia	6 N-m	Robonist INDIA	BOSCH	18 N-m	DENSO India	6 N-m	Robonist INDIA

The proposed DC geared wiper motor arrangement as seen in Table 1 has a slider crank mechanism which drives a rack-pinion to rotate the wiper. The results have been generated for the autorickshaw wiper system at a speed of 70 rpm using both the systems as shown in Table 1.

The curves showing the displacement of rack, velocity of rack and acceleration of rack is given in the Figure 5 below.
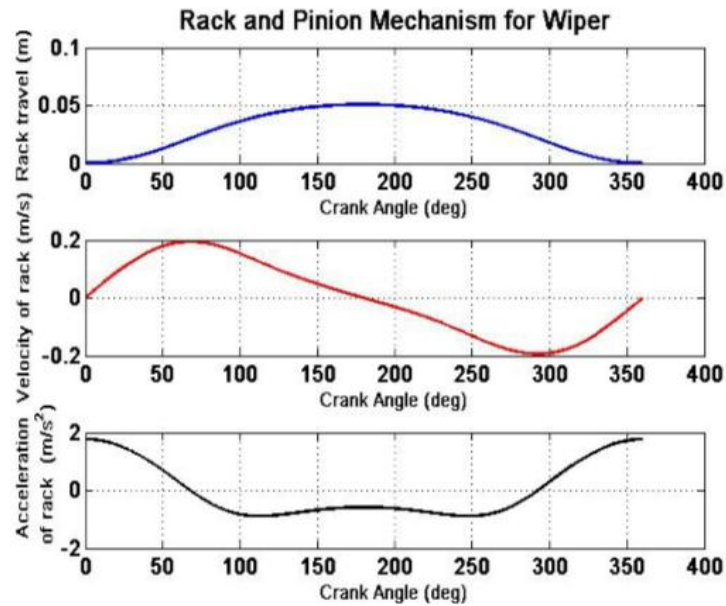

Figure 5– Response of the slider crank mechanism actuating the rack

The performance of the DC geared wiper motor is compared with the conventional wiper motor and the results are shown in Figure 6 below.
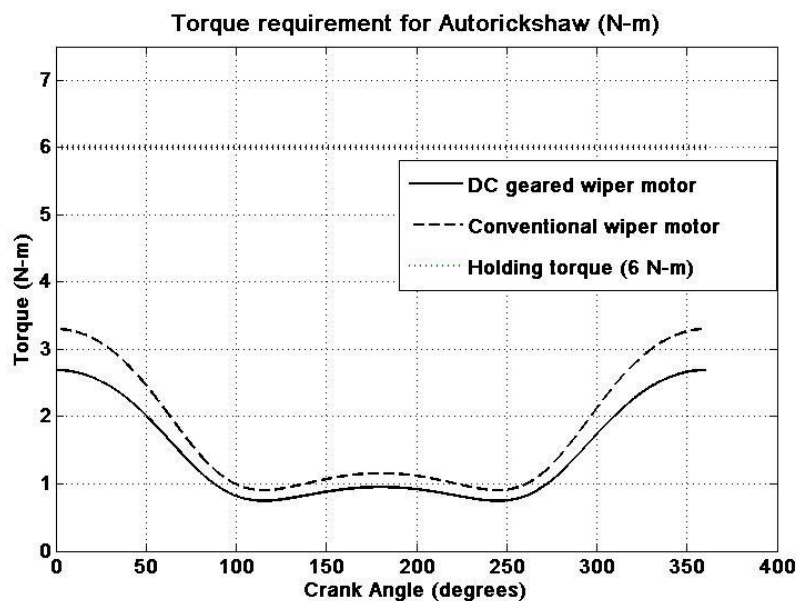

Figure 6– Torque demand curve for the wiper systems at 70 rpm

As seen in Figure 6, the torque required by the DC geared motor wiper is large at the starting point and then reduces as it approaches the mean position. The torque required by the DC geared motor arrangement is 18% less than that required by the conventional wiper motor. The force required is maximum at the extreme position and reduces towards the mean positions.
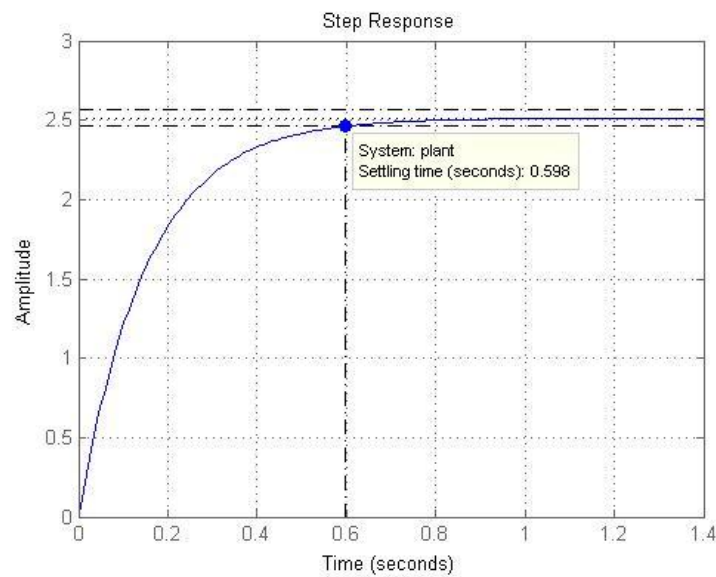
Figure 7 – Response time for rack and pinion mechanism

The rack and pinion arrangement are modelled as a first order transfer function with a time constant of 200 ms. As seen in Figure 7, the step response of the rack and pinion mechanism is seen, the settling time for 2% is 600 ms which can be considered as the 95% response time for the mechanism to track the reference velocity.[8]
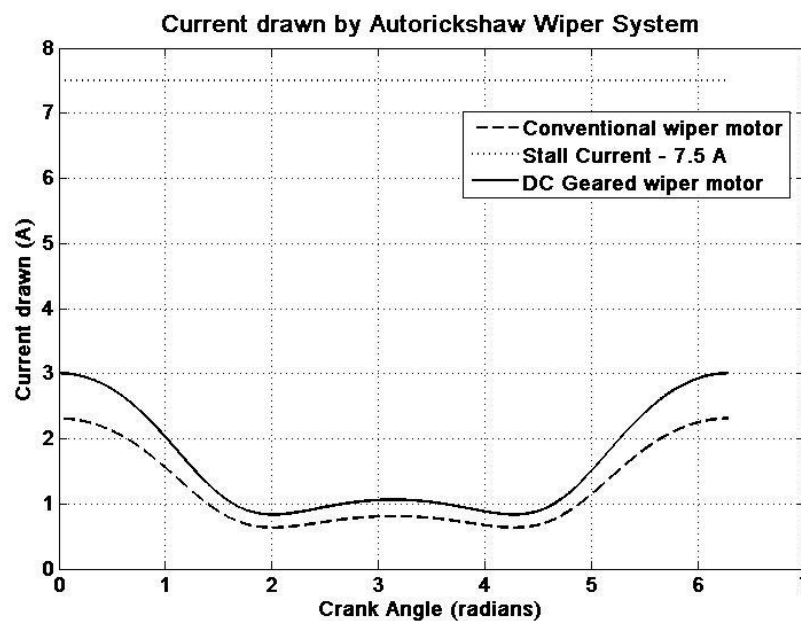

Figure 8 – Current drawn for Lucas wiper motor and DC geared motor at 70 rpm

As seen in Figure 8, the current drawn by the Lucas motor arrangement is 30 % less than the current drawn by the DC geared wiper motor arrangement. Hence, for a given power source, the DC geared wiper motor arrangement will have a 24% shorter life as compared to the conventional Lucas wiper motor arrangement. This is a compromise as compared to the gain in other parameters like torque requirement, weight reduction and size of the compact arrangement. The conventional wiper motor is over designed for the existing operating conditions and hence, the proposed DC geared system will work to optimise the performance.

EXPERIMENTAL VALIDATION OF AUTORICKSHAW WIPER SYSTEM

This section shows the experimental validation of the DC geared wiper system where the DC geared motor is attached to a rack and pinion arrangement [9] which drives the wiper. As seen in the video available at the link given in [10], the motor with a stall torque of 3.8 N-m and a stall current of 7.5 A can run the wiper and thereby provide continuous wiping action like the conventional arrangement.

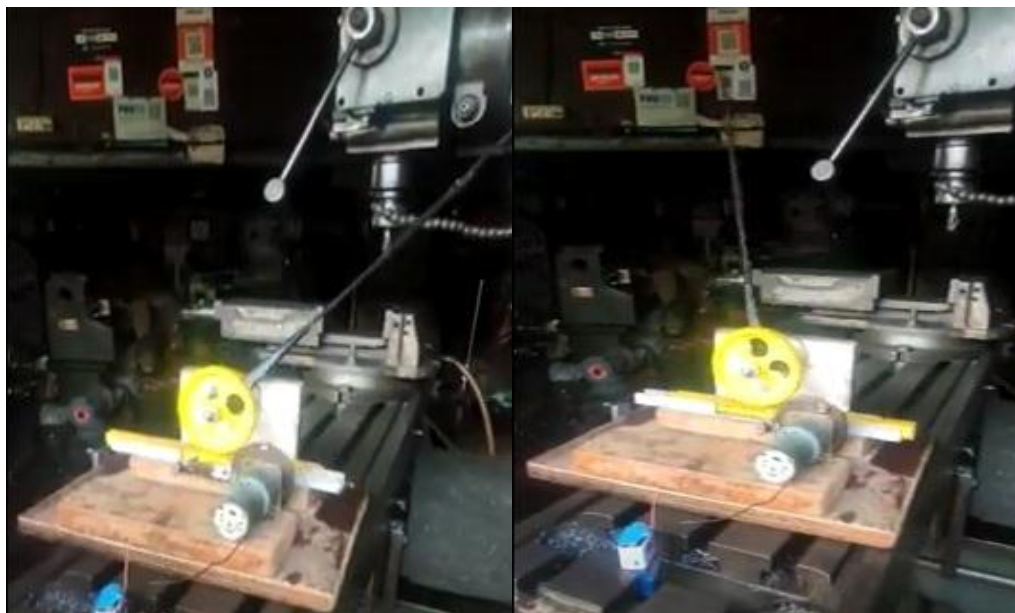Figure 9-a – Snapshot of video showing voltage and current of ERS wiper system

Figure 9-b – Wiper at 2 seconds Figure 9-c – Wiper at 5 seconds

Load, L_0 = DC geared motor driving slider crank mechanism and rack in channel

Wiper speed (observed) – 11 revolutions in 9 seconds

Hence, Wiper RPM, N = 11x60/9 = 70 rpm

Supply voltage, V_{L0} = 12.2 V

Current with existing load, I_{L0} = 0.34 A

Additional load on motor ΔL = Pinion driven by tangential force of rack and driving the wiper blade on windshield including friction of 0.8 N
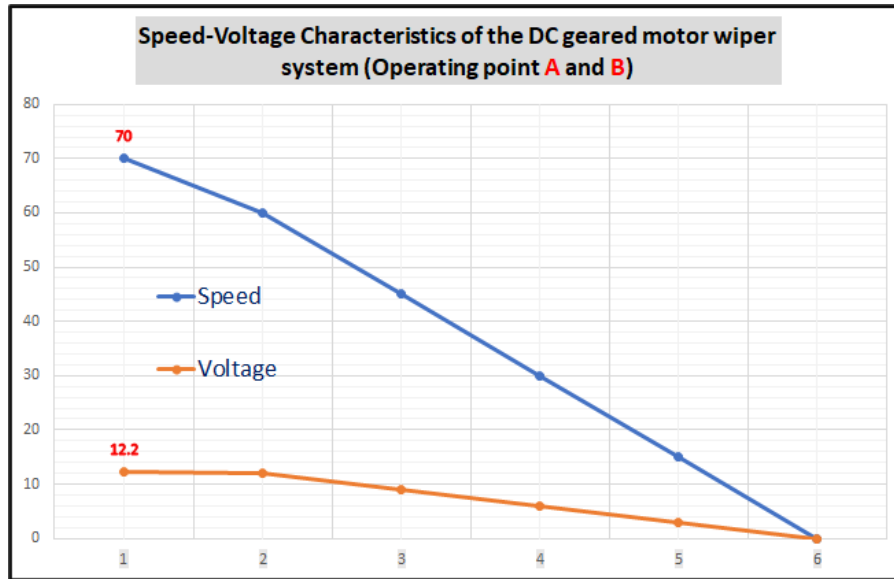
Figure 10 – Initial operating point A of the ERS Wiper System running at 12.2 V and 70 rpm and final operating point B with the same parameters
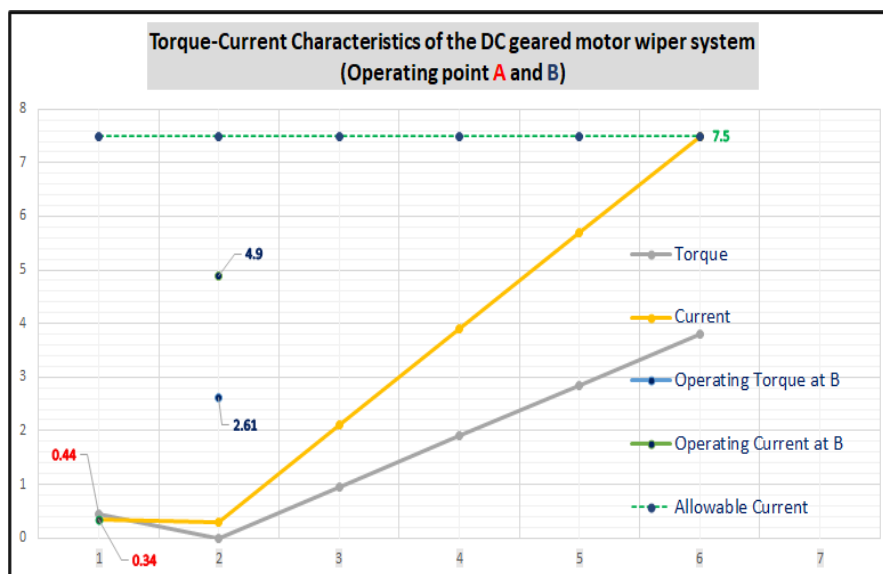

Figure 11 – Initial operating point A of the ERS Wiper System running at 0.44 N-m and 0.34 A and final operating point B with T = 2.61 N-m and I = 4.9 A.

Operating Point A – Motor loaded with slider-crank mechanism and rack (see Fig 10)

As seen in Figure 9 above, when the motor with the load of rack and slider crank is run, it consumes a current of 0.34 A at a supply voltage of 12.2 V. The rated voltage and speed of the motor is 60 rpm at 12 V. Hence, the motor is running at around 70 rpm at this voltage. The no load current is 0.3 A while with the load of rack + slider + crank, the current increases to 0.34 A.

Operating point B (rack + pinion + wiper (including friction)) (see Fig 11)

Frictional force Fr = 0.8 N,

Hence, equivalent frictional mass, m_f = 0.8/9.81 = 0.082 kg

Angular velocity, w = 2*pi*N/60 = 7.33 rad/s; where N = 70 rpm
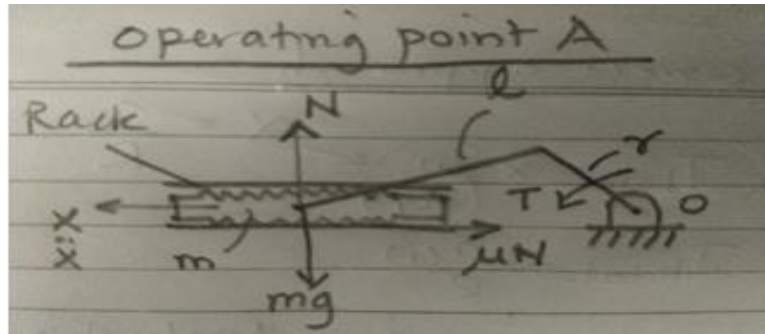
Figure 12 – DC geared motor actuating rack (Operating point A)

Total inertia reflected at the rack

$J_{total} = J_{wiper} + J_{pinion}$

$= m_{wiper}*L^2/3 + m_{pinion}*R^2/2$ where R-radius of pinion, L – length of wiper arm

$= 0.25*0.4\char94 2/3 + 0.06*0.04\char94 2/2 = 0.0134$ kg-m^2

Mechanics of the maximum torque due to rack

$N = mg$;

In extreme position as seen n Figure 12 above, distance from pivot O is $l + r$.

Hence, $T_{max} = N (l + r) = mg (l + r) = 0.06 \times 9.81 \times (0.05 + 0.025) = 0.044$ N-m

Incremental Load torque calculation

$J_{total} = 0.0134$; % increase in inertial load due to pinion and wiper

$T_f = 0.8$; % considering frictional torque due to frictional load - 0.8 N

$T_{rack} = 0.044$; % maximum load on motor due to rack

$T_L = J_{total} *Ÿ/R + (W – T_f) *(L/2) *cosβ + T_{rack}$ where Ÿ = acceleration of rack

The maximum load torque comes out to be 2.61 N-m which is less than the stall/holding torque of 3.8 N-m, also, the current drawn is 4.9 A which is less than the maximum allowable current of 7.5 A, hence design is SAFE AND OPERATIONAL. *Similar results will be found using the wiper parameters for the compact car/sedan.*

CONCLUSIONS, SALIENT FEATURES AND FUTURE WORK

The proposed research work carried out in this paper shows that a normal DC geared motor arrangement along with a slider crank and rack-pinion mechanism can very well drive the wiper of an automobile. Since, the electrochemical reaction is spontaneous, the actuation by this kind of a cell will results in very less response time from the time of contact of the rainwater with the cell. (**approx. 750 ms**). The DC geared motor consumes almost **18% less torque** than the conventional Lucas motor and runs with very minimal parts. Also, **62.5% weight reduction** by replacement of Lucas motor with a geared DC motor and the easy off the shelf availability of the rack and pinion setup are a lucrative point to choose this alternative. Compactness of this arrangement as seen in Figure 2 and 1 which has dimension of 18 inches to a reduction of 6 inches which is **1/3rd the original size** is a great advantage for the auto industry. In the proposed arrangement, there is **30 % more consumption of current** as compared to the conventional Lucas wiper motor arrangement which is the only compromising factor. This will lead to a **reduced battery life of 24%**. However, with the use of renewable energy sources like solar and rainwater, this energy difference can be very well recovered. With the alternative wiper system, there is around **cost reduction is 50% per vehicle**. Furthermore, a suitable ARAI standard compatible product will be designed. Pilot project on an actual existing compact car will be carried out to prove the effectiveness of the technology. **The wiper motor recommended for both the autorickshaw and compact sedan is having a stall torque of 6 N-m and a stall current of 7.5 A.** The benefits of the technology can be seen if implemented by car companies on a large scale.

The salient features of this new proposed system are tabulated below

Parameter	% w.r.t. Conventional Lucas Wiper Motor
Wiper motor torque	18% reduction
Wiper motor weight	62.5% reduction
Current consumption	30% increase
Dimensions or Size	67% reduction
Battery life	24% reduction
System response time	750 ms
Cost	50% reduction

ACKNOWLEDGEMENTS

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