DESIGN OF AN ELECTROCHEMICAL BASED RAIN SENSING (ERS) WIPER SYSTEM FOR LOCAL TRANSPORT

(Comparison of performance of conventional Lucas wiper motor with geared DC motor)

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Abstract : *The conventional wiper system in an automobile is operated by the Lucas motor (12V heavy duty) and is connected to the micro-controller of the vehicle. In places like Mumbai, where there is heavy and persistent rainfall, such systems can malfunction due to water logging in the vehicles. In this paper, we propose an electrochemical based rain sensing wiper system which is very sensitive to the rainfall and works with minimal electronics and is independent in operation of the micro-controller of the vehicle. The main component of the system is an electrochemical cell having an accordion joint salt bridge made of straw which is modeled as a mass-spring-damper system and which produces a deflection of 3.2 μm under the impulse force of a single raindrop. When the circuit is completed due to deflection of the salt bridge, it generates sufficient current which is fed as input to the set of transistors in Darlington configuration making the wiper to run at the rated speed and also performs other functions like opening/closing of windows and doors. A solar charged 12V DC battery can be used to supply the necessary voltage to the wiper.*

Index Terms **- rain sensing; electrochemical; accordion salt bridge; wiper.**

INTRODUCTION

During 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 that works on a principle other than electronics and independent of the micro controller 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. Situations such as sudden rain can cause the driver to panic resulting in him pressing some wrong button in-order to start the wiper. A low cost automatic rain sensing wiper will be very useful in such a scenario.

In developed nations, when the vehicle is left in the open and a snowfall occurs such a system would turn on the wipers and scrub the snow. When the ignition is turned off the wiper still keeps on running allowing for better visibility for the driver. The shut off ignition should close the opening for the water thereby stopping the wiper. The literature review [1-4] and working principle of various existing automatic rain sensing wiper technologies are discussed in detail in Table 2 in Section 3 of the paper.

DESIGN OF IN-SITU ELECTROCHEMICAL RAIN SENSOR (ERS)

The in-situ electrochemical sensor as seen in Figure 2 below is made using the conventional technique. Two electrodes of Cu and Zn are placed in their respective electrolytes. In-order to complete the circuit, a salt bridge is made using the following procedure.

Procedure For Making Accordion Joint Salt Bridge

The salt bridge acts as a connector between the electrolytic solutions and thereby completes the circuit. Basically the salt bridge is in the galvanic cell to regulate the charges in solution and keep them neutral. Without this, there is no flow of electrons, and therefore no electrical output. It avoids voltage drop. The standard procedure of making a salt bridge is enlisted below:

α) Prepare about 150 ml of distilled water in 400 ml beaker and bring to boil.
β) Take 3 g agar-agar powder and stir the mixture as the suspension boils
χ) Remove the beaker from the heat and stir in 15 g KCL until the salt dissolves.
δ) Pour the warm mixture in the bent straw salt bridge until it is completely filled. Once agar is set, store in plastic bag for preventing drying out.
ε) Seal one end with cotton plug and ensure that no air bubbles are present in the salt bridge prepared.

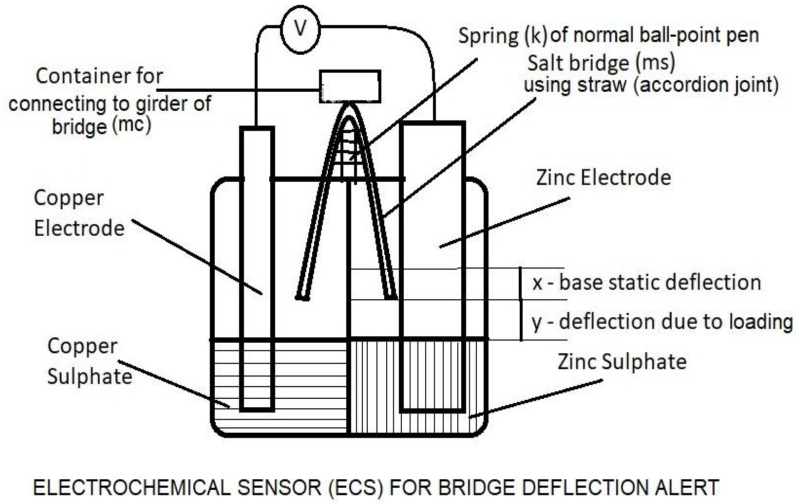

Figure 2. – Electrochemical Rain Sensor (ERS)

Working of Electrochemical Rain Sensor (ERS)

The electrochemical alert sensor is modeled as a mass-spring-damper system as shown in Figure 1 above. The parameters used in the design of the electrochemical sensor are given in Table 1 below. The static deflection due to the container, salt bridge and spring is 51.4 μm. In-order to test the sensitivity of the sensor, raindrops were considered as a forcing input.[6]

Diameter of raindrop – 3 mm, Terminal velocity – 8 m/s, Time taken to come to rest – 80 ms

Force generated due to impulse = mv/t = (1000 x π x $(0.003)^3$ x 8)/ (6 x 0.08) = 1.41 mN

Every raindrop generates an impulse force of 1.41 mN resulting in a deflection of 3.2 μm of the assembly (container + salt bridge + spring) which slowly reaches to static deflection in about 1.2 s. This was in consideration with the value of damping of air, ζ_{air} = 0.01 while in practice air has almost negligible damping and will continuously produce a sinusoidal oscillation of amplitude 3.2 μm.

Table 1. Parameters for the Electrochemical Rain Sensor

Parameter	Value	Unit	Availability
Mass of container (m_c)	1.47	gm	General purpose container to give medicine to children and adults (10 ml)
Mass of salt bridge (m_s)	3.5	gm	Normal straw with center bend (accordion joint)
Mass of spring (m_k)	0.17	gm	Used in normal ball-point pen
Stiffness of spring (k)	950	N/m	NA

The steady state response to raindrop force can be seen in Figure 2 below. The cell will continue to generate current while it is raining and will stop when the rainwater in the container drains out. The deflection 'y' can be adjusted to allow for suitable amount of rain water being collected in the container thus adjusting the sensitivity of the ERS. Sample calculation of the sensitivity of the cell is explained in the next section.

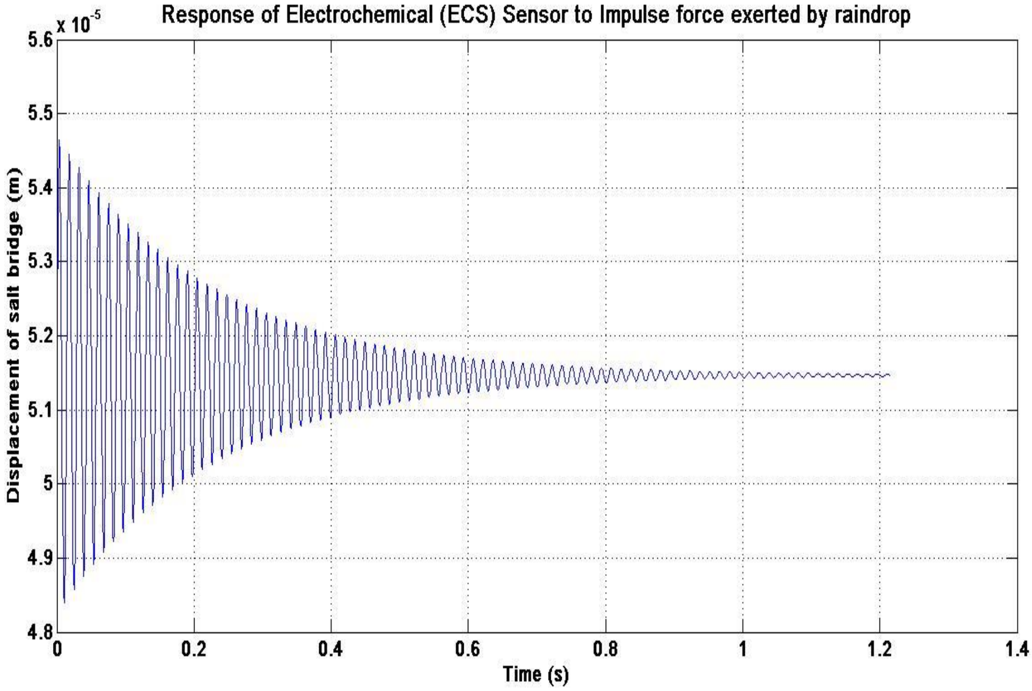

Figure 3 – Time response of ERS to a impulse force created by a raindrop

Sample Calculation of Sensitivity of Electrochemical Rain Sensor (ERS)

Volume of 1 raindrop = $\pi D^3/6\ m^3$

Allowable deflection/threshold = y_{allow}

Steady state oscillation due to single raindrop = 3.2 µm

Steady state response due to N raindrops = 3.2N µm

Total deflection due to 'N' raindrops = N x $1000g\pi D^3/6$ µm (Static deflection) + 3.2N µm(oscillatory assuming all in-phase)

Assume the time between successive raindrops be 1 second; then

y_{allow} = N x $1000g\pi D^3/6k$ µm + 3.2N µm

For D = 3 mm; k = 950 N/m

y_{allow} = 0.148N + 3.2N

N = ROUND(y_{allow}/3.348)
Sensitivity of ERS, S = 3.2/Volume of 1 raindrop (ml) = 3.2/0.0141 = 227 µm/ml
Time to response = N-1 seconds

So, for a threshold value equal to a thickness of an A4 paper, y_{allow} = 50 µm which gives N = 15 with a response time of 14 seconds assuming a spacing of 1 s between raindrops.

Useful Life Of The Electrochemical Rain Sensor (ERS)

The sensor produced in the manner as described above is very light in weight and sensitive to small disturbances. Also, due to the field environment, the sensor may lose its capability of sensing. Due to changes in ambient temperature, the salt bridge characteristics may change and thereby make the sensor malfunction. Hence, in-order to understand the exact behavior of the sensor, we conducted a test for determining the average lifespan of the sensor when it is continuously in the conducting state.

The experiment was conducted with an accordion salt bridge over a period of 18 days using 0.1 M solution of each of the electrolytes $CuSO_4$ and $ZnSO_4$. The voltages and current were measured at different time intervals. The measured voltages and current were used to compute the actual power of the sensor(cell). The theoretical time for the cell life was computed as given below:

Cell life in days = (No of cells x Molarity x Volume (liters) x No of electrons/mole x 96485)/(60 x 60 x 24 x (Final current + Initial current)/2))

The theoretical current is taken to be average of initial and final current value. The theoretical cell (sensor) life turned out to be 22.9 days. The actual experiment worked for 18 days (432 hours). The performance of the ECAS is as seen in Figure 4 below. The actual curve of the current indicates that the ECAS will discharge as a battery in an exponential manner. The voltage provided by the ECAS is almost constant at 1.04 V which is less than the expected value of 1.1 V due to polarization effects.

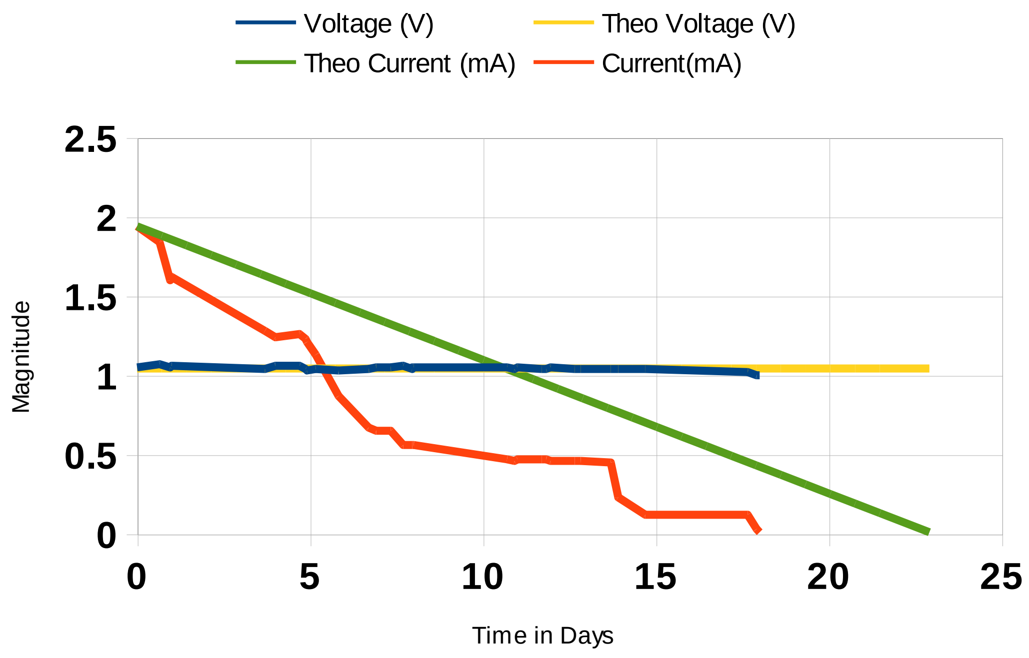

Figure 4. – Performance of ERS (Cu-Zn Voltaic cell with accordion salt bridge in 0.1 M 100 ml solutions)§

The current of ECAS gradually drops following an exponential curve like the discharging of a voltaic cell. As seen in Figure 4 above, we can confidently say that the ERS will work in a continuous state of conduction for a period of 15 days where the current drops to 0.1 mA.

Comparison Of The Electrochemical Rain Sensor (ERS) with other sensors

The following table explains the comparison of the ERS with various other sensors and has been published in literature[7]

Table 2 - Comparison of various rain sensors

	DIFFERENT TYPES OF RAIN SENSORS				
	Plate based sensor[2]	**Piezo-electric sensor[1]**	**Probe based sensor[4]**	**Optical based rain sensor[3]**	**Electro-chemical rain sensor[7]**
Operating principle	Micro controller based	Micro controller based	External circuits connected to micro controller	Micro-controller based	Independent of micro controller
Working	Small drops of water change the resistance	Water between plates decrease resistance	Contact of water with probe completes rain circuit	Change in reflection due to rain water	Rainwater energy is converted into displacement of electrochemical switch
False rain detection rate	Very high	Less than 5 %	Less than 2 %	Less than 2 %	Less than 2 %
Voltage required	12 – 5 V DC	12 – 5 V DC	2 – 6 V DC	12 – 5 V DC	1 – 3 V per single cell
System response time	Not mentioned	500 ms after rain contact	On collection of 10 cu.cm	Very low	550 ms after rain contact
Sensor surface size	Very large	<= 4 cm x 4 cm	>=2.58 cm x 2.58 cm	Not applicable	1 cm x 1 cm

§ *The data for the Cu-Zn cell can be shared upon request and proper authorization from Rizvi College of Engineering (RCOE)*

	DIFFERENT TYPES OF RAIN SENSORS				
	Plate based sensor[2]	**Piezo-electric sensor[1]**	**Probe based sensor[4]**	**Optical based rain sensor[3]**	**Electro-chemical rain sensor[7]**
Placement of sensor	On the windshield	On the windshield	Inside the font hood	Inside the car cabin	Inside the front hood
Cost of replacement	Quite high	Quite high	Around Rs 1000	Around Rs 7000	Around Rs 1500
Adaptivity	Changes the aesthetics of the vehicle	Embedded on windshield	Volume of rain collected is high	Seamless integration with vehicles	Adaptable to all vehicles

APPLICATION OF THE ERS SYSTEM TO THE WIPER MOTOR

The following sections discuss in detail the two types of arrangements for the operation of the wiper motor using

1. Conventional Lucas Wiper motor arrangement [8]
2. DC Geared Wiper motor with Rack-pinion mechanism [7,9]

Comparison Of The Lucas Wiper Motor and the ERS based wiper motor

The conventional wiper motor assembly is as shown in Figure 5 (a) below. The wiper motor assembly developed at Mechatronics Lab, RCOE using a DC geared motor and a rack-pinion mechanism is as shown in Figure 5 (b). The normal wiper motor operates at two speeds of 45 rpm and 60 rpm.

Figure 5 (a) Lucas wiper motor (b) Electrochemical based rain sensing wiper system

Table 3 – Parameters of the two configurations

Parameters	Conventional Lucas Wiper Motor [8]	DC Geared Motor with rack-pinion [7][9]
Weight of wiper arm	330 gms	330 gms
Length of wiper arm to pivot	450 mm	450 mm
Crank rod length	NA	25 mm
Connecting rod length	NA	50 mm
Diameter of pinion	NA	79 mm (Module 1.41, Teeth – 56, Pitch - 18)
Length of rack	NA	100 mm
Weight of motor	800 gms	180 gms
Stall torque of motor	180 kg-cm	80 kg-cm
Stall Current	14 A	7.5 A

The torque required at 65 rpm for a wiper rod of length 450 mm with a mass of 330 gms is as shown in Figure 6 below. The wiper is modeled as a rotational load along-with the rack and pinion which can suitably generate the required trajectory. Frictional force is considered to be 0.8 N [5].

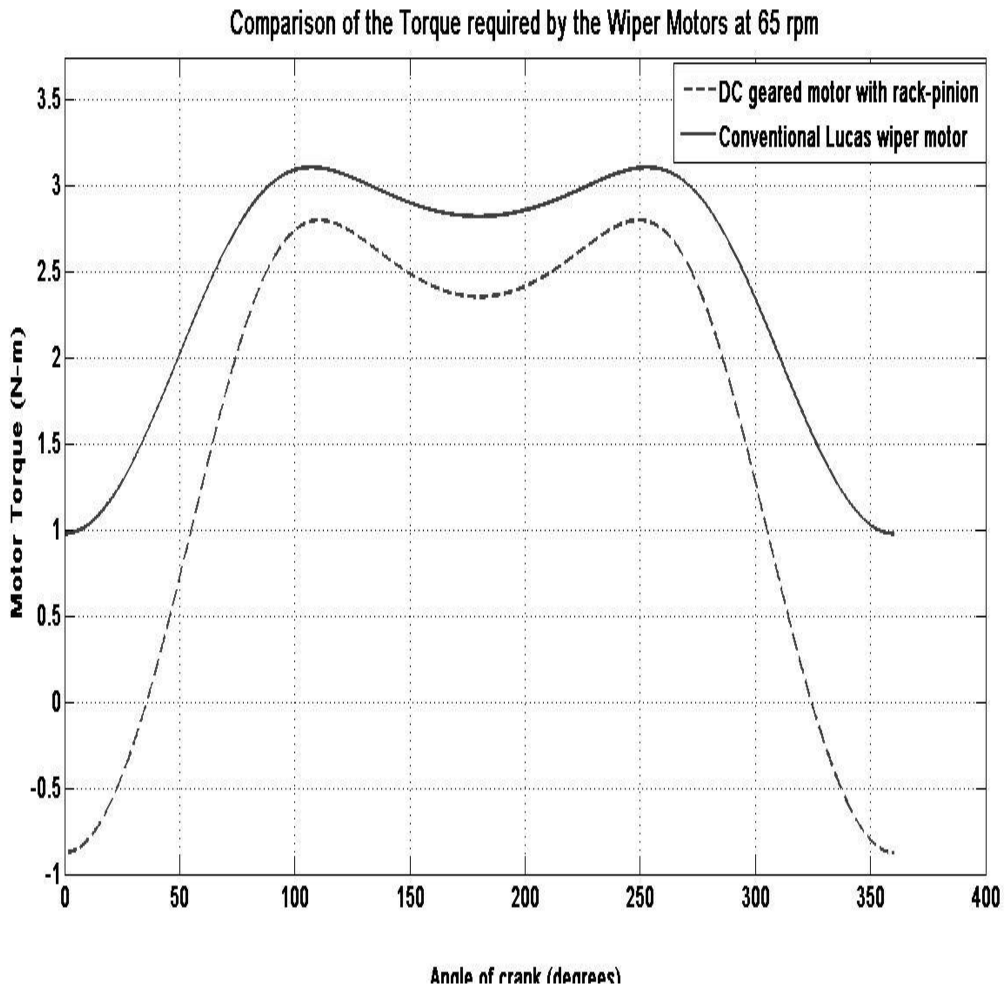

Figure 6 – Comparison of motor torque for Lucas wiper motor and DC geared motor at 65 rpm

Schematic of the proposed Electrochemical based Rain Sensing Wiper System

The Figure 7 below shows the detailed connections for the implementation of the Electrochemical based rain sensing wiper system.

As the impulse force due to the raindrops causes the salt bridge to connect with the electrolytes, the current is generated which is fed to the base of transistor with hFe = β_1. The base of the transistor is connected to the ERS which has to generate more than 1.4 V for both the transistors in pair configuration. This is achieved by a Cu-Al voltaic cell (cell voltage = 2 V) combination whose results will be similar to those mentioned for the ERS above. The general purpose transistor BC547 has a hFe from 100-800. For a BC547-C Series value of 600, the transistor can supply enough current to run the wiper at 45 rpm (requires 1.2 A). In-case of 65 rpm (requires 1.47 A using ERS), there will be an additional salt bridge that will get connected thereby supplying current upto 2.6 mA to the base, resulting in an output available current of 1.56 A ensuring successful operation of the wiper at 2 speeds. The voltage at 45 rpm is 9 V which is got from a voltage regulator.

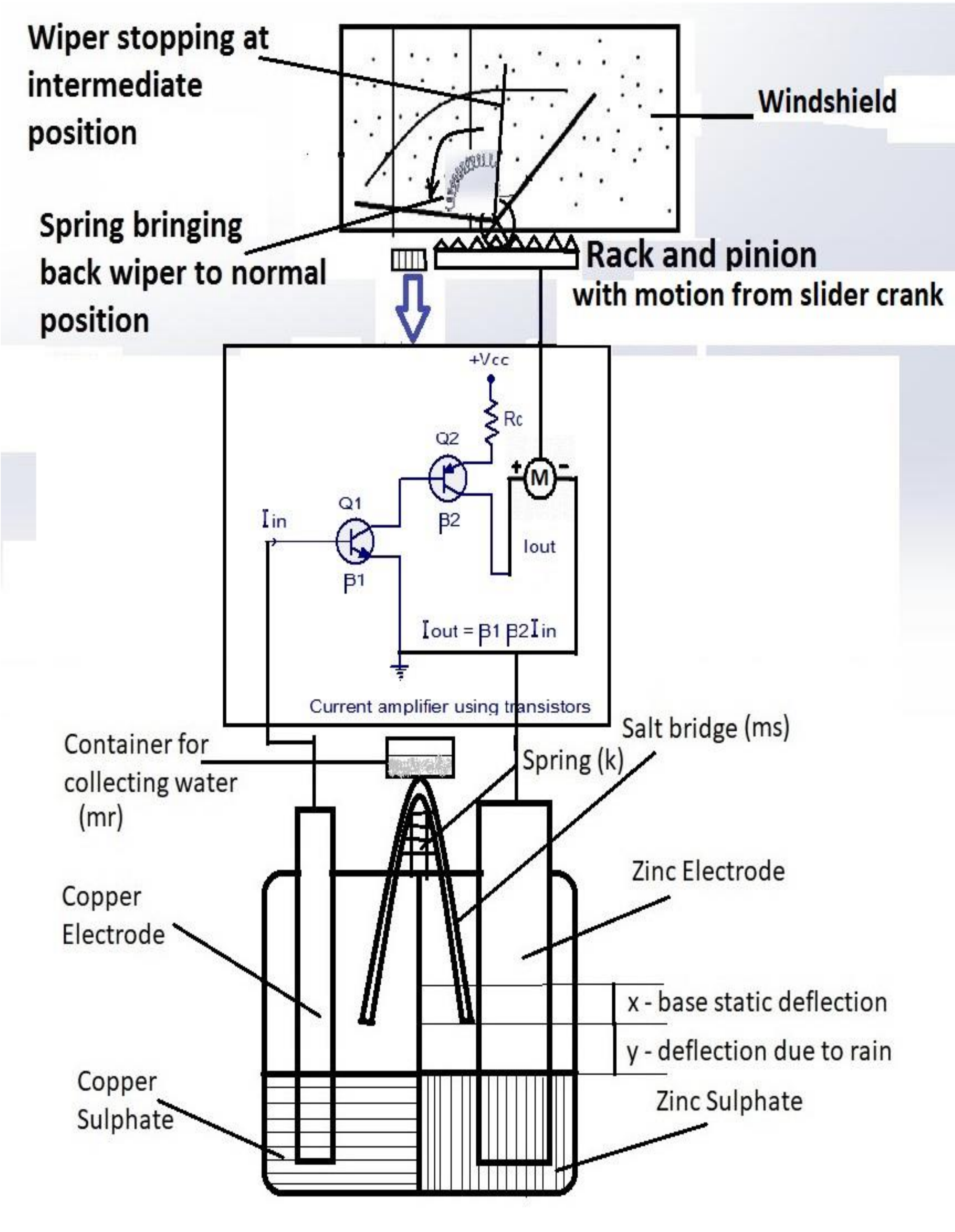

Figure 7. – Connections for ERSW system

The transistors in Darlington pair, causes the current to be amplified by a factor of $I_{out} = \beta_1 * \beta_2 * I_{in}$. This huge magnified current can be used to drive other applications like door opening/closing and windows opening,etc at higher speeds of rainfall. The voltage supply $+V_{cc}$ is a 12V battery that is charged through a solar panel. The base of both the transistors need to be in forward bias condition for which the voltage across the P-N junction must be greater than 0.7 V each. ie.1.4 V. Hence, the cell to be used is an Cu-Al cell which generates a steady voltage of 2 V instead of the Cu-Zn combination.

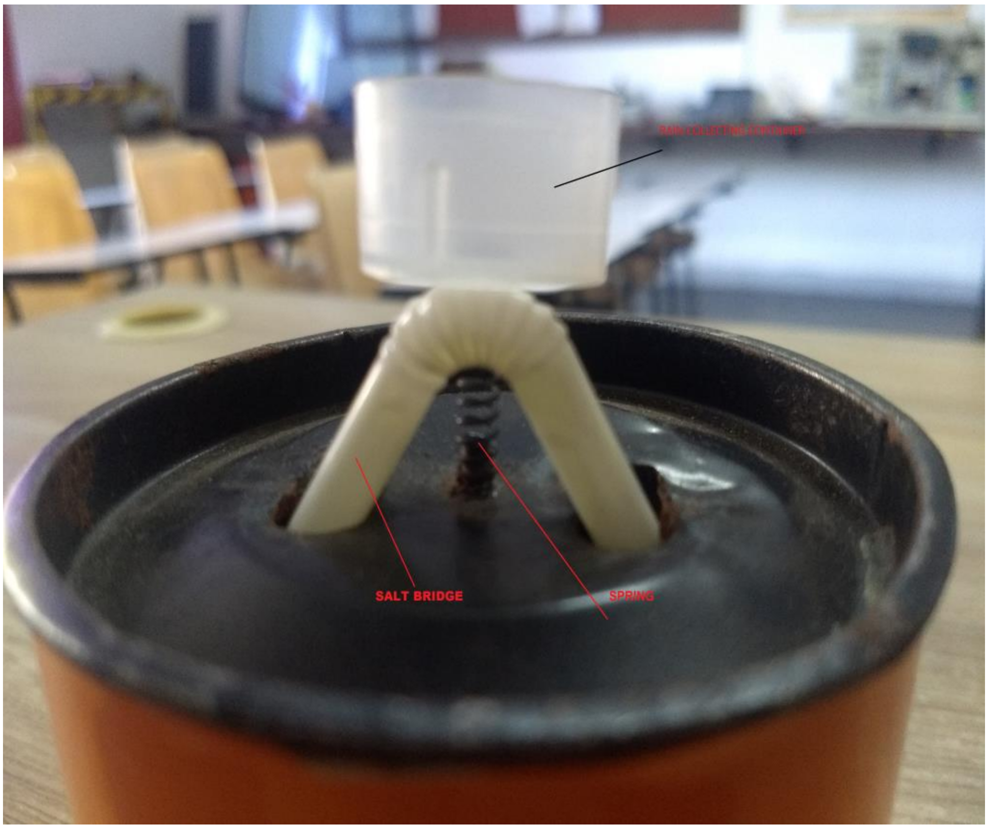

Figure 8 : Electrochemical Rain Sensor from waste materials

Table 4 : Comparison of the two configurations for wiper motor systems carried out in MATLAB2014a

Motor Configuration	45 RPM		65 RPM		100 RPM	
	Max Torque (N-m)	Max Current drawn (A)	Max Torque (N-m)	Max Current drawn (A)	Max Torque (N-m)	Max Current drawn (A)
Conventional Lucas Wiper motor arrangement[8]	2.94	1.54	3.11	1.63	3.6	1.874
DC Geared Wiper motor with Rack-pinion mechanism[7]	2.28	1.2	2.8	1.47	4.16	2.21
% Change in parameter from conventional arrangement	**-22.4**	**-22.07**	**-10**	**-9.81**	**+15.6**	**+16.58**

As seen in Table 4 above, the torque required by the DC geared motor arrangement is quite less as compared to the conventional Lucas motor for the 2-speed arrangement. In-case of the 3rd speed at 100 rpm, the torque required by the DC motor is quite large as the inertial effects at higher acceleration of the wiper become pre-dominant. The Lucas motor however, being a high torque motor draws less current at 100 rpm.

CONCLUSIONS AND FUTURE WORK

The sections above discuss the technological aspects of the Electrochemical Rain Sensor (ERS) based wiper system and is compared with the existing conventional wiper system developed by Lucas. Since, the electrochemical reaction is spontaneous, the actuation by this kind of a cell will result in very less response time. The DC geared motor consumes almost 10% less current than the conventional Lucas motor and hence, will result in longer life of the wiper system for a given battery supply. Also, the weight of the motor and the easy availability of the rack and pinion setup are a lucrative point to choose this alternative. Experimental verification of the same is a part of future work.

Furthermore, a suitable ARAI standard compatible product will be designed. The sensitivity of the product will be compared with the existing products in the market. Pilot project on an actual existing compact car will be carried out to prove the effectiveness of the technology. Also, suitable maintenance procedures and manuals will be designed so that the technology transfer to existing car companies or OEMs or Car Service Centers can be easily carried out. The benefits of the technology can be seen if implemented by car companies on a large scale. Furthermore, following enhancements will be done in due course of time which will lead to value addition of the above rain sensing wiper :

1. Automatic speed control of wiper based on rate of rainfall
2. Automatic mist and fog removal
3. Automatic rolling down of windows.
4. Testing of response time after rain contact
5. Design of parking mechanism for wiper
6. Design of vibration isolation system for cell and effect of temperature on the performance.

The introduction of this new type of system in current cars needs to also be checked in terms of its effect on the fuel economy especially the effect on reduction in usage of air-conditioning and the gains/losses that it has as compared to an existing rain wiper system.

ACKNOWLEDGMENT

We would like to express deepest appreciation towards Dr. Sujata Rout, Head of Mechanical Department whose invaluable guidance supported us in this project. Also, we would like to thank Mr. Bhaskar Gareg for providing us with the windshield free of cost that motivated us in conducting this experiment. We would like to thank Mr. Milind Sanzgiri from Asha Scientific who helped us by providing us with suitable electrodes for our experiment. At last we must express my sincere heartfelt gratitude to all the student members of Mechanical Engineering Department, Electrical Engineering Department and Chemistry/Humanities and those actively associated with Mechatronics Lab, RCOE who helped us directly or indirectly during this course of work.

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