Development of Torque Sensor Based Electrically Assisted Hybrid Rickshaw

A Thesis
Submitted to the Department of Electrical and Electronic Engineering
Of
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DECLARATION

We hereby declare that research work titled "*Development of Torque Sensor Based Electrically Assisted Hybrid Rickshaw*" is our own work. The work has not been presented elsewhere for assessment. Where material has been used from other sources it has been properly acknowledged/referred.

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ABSTRACT

Cycle rickshaws are the most popular form of transportation inside the cities of Bangladesh, especially for its route and time-flexibility and door-to-door services. Considering the fact that a significant portion of underprivileged population of Bangladesh is directly or indirectly dependent upon the rickshaw-pulling profession, the necessity of scientifically thinking about its improvement and modernization was apparent. This paper describes a research and development project of Control and Applications Research Group, BRAC University, aiming to modernize these green fuel-free transports of Bangladesh using power-assistive technology. This involves design and implementation of an intelligent control system that would make the rickshaw pulling task easier-to-feel by assisting the human power with a motor, turning it into a hybrid vehicle. The motivation of the project was to relieve the rickshaw pullers from the excessive physical exhaustion associated with the task, which mainly occurs while initiating the momentum from rest or low speed to a moderate speed. A motor helping the pullers only during this particular time eradicates this exhaustion to a significant extent, at the same time saves energy by limiting over-use of the motor. A torque-sensor was involved to determine the need-of-assistance a puller feels at a particular time, and an external controller in addition to the motor controller was designed and tested. The model was developed so as to save energy, limit overuse, and keeping the identity and driving mechanism of old rickshaws. An idea of battery charging infrastructure using Solar-Battery-Charging-Station is also mentioned as a core factor of the project.

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ABBREVIATIONS

BLDC- Brushless Direct Current
TPS- Throttle Position Sensor
CU- Control Unit
TS- Torque Sensor
CIT-Controller Input Terminal
MOSFET-Metal Oxide Semiconductor Field Effect Transistor

CHAPTER 1

Introduction

1.1 Introduction to the Rickshaws

Cycle rickshaws, mainly because of their short-trip suitability, lower road-space occupancy, mobility in narrow-roads, route-flexibility, door-to-door services and relative cost-effectiveness compared to private transports, are the most popular and socially preferred form of transportation in most of the cities of South Asia, especially Bangladesh. This non-motorised form of public transport is basically a three wheeler vehicle capable of carrying two passengers excluding the driver, or a pay-load of 150-200 kg [1]. These rickshaws are run totally with the muscular energy the rickshaw driver (also known as the Rickshaw puller) applies on the pedal. The two basic forms of rickshaws, one for carrying passengers and another exclusively for freight carriage (also known as ‘van-gari’) are shown in Fig. 1.

Fig. 1.1 Rickshaw-van [8] **Fig. 1.2 Passenger rickshaw [9]**

Fig.1 Rickshaws, as seen in the streets of Dhaka; source: [8], [9]

In Dhaka, most of the trips are short with an average trip-length of 3.8 km [2]; and also the number of people travelling together is usually short. Rickshaws are extremely competitive in these situations in-terms-of total travel-time and cost. In a city like Dhaka, door-to-door mobility provided by Rickshaws is significantly important especially to the vulnerable social groups – women, children and elderly [3]. The statistics indicate that in Dhaka nearly 40% of the loaded rickshaws are being used by women and children, or people with goods. Another 30% of users are students [2]. In addition, they provide an easily-available alternative to the high costs for taxis and auto rickshaws, and to the poor operating characteristics of motorized public transports likes minibuses and tempos.That is the reasons why it is popular among major strata of the society. It is also an important fact that most of the rickshaw passengers come from upper-middle to lower-middle income groups.

1.2 Impact of Rickshaws in the Economy of Bangladesh

34% of the contribution from the transport sector to the GDP of Bangladesh is from the Rickshaws [4], [5]. In Dhaka alone, approximately $300,000 is transferred between rickshaw-pullers and passengers everyday [4], [6]. It is estimated that there are around 2 million rickshaw pullers in Bangladesh [6] and around 19.6 million (14% of total population) indirectly relies on rickshaw-pulling business (their families, manufacturers, garage owners, painters, repair-men) [7]. An astonishing fact is revealed by a research [25] which shows that an average income is decreased by 15% for a job shift from rickshaw pulling to others. In Dhaka alone, 20% of the population directly or indirectly relies on rickshaw pulling sector which is about 2.5 million people. [7] This figure is also expected to increase by 2012 significantly. These statistics clearly indicate that a deep thought should be given in handling this amount of manpower and turn them into ‘human-resources’ for the country.

1.3 Motivation

The motivation towards working on this research and development program was originated from the view that a massive modernization in this sector will not only improve the living standard of a huge number of people involved in rickshaw pulling, but also improve the quality of life of upper and lower-middle income groups of urban inhabitants. It will also create more economic sectors associated with it, like the ‘Central Solar Battery Charging Station’ (to be associated with the project in a later phase).

Relieving the Rickshaw-pullers from tremendous physical exhaustion by assisting them electrically, limiting overuse of electrical energy by introducing a torque sensor, using the available resources (present rickshaws) for transformation into a perfectly “hybrid” vehicle, rather than manufacturing brand-new ones, creating a charging infrastructure primarily powered by renewable energy, and ultimately, decentralizing people from Dhaka city – these were the major motives of this project.

1.4 Problems with the Traditional Rickshaws

In many parts of Dhaka, roads that can hardly bear three lanes for cars; have rickshaws, private cars and buses clustering and causing traffic jam and minor road accidents on a regular basis. The alarming statistics of the rickshaw population is already mentioned. Being a slow-speed, muscle driven vehicle; Rickshaws are often blamed to be the cause of traffic jams in cities like Dhaka; and to not provide enough earnings for the pullers in contrast to the immense physical strain involved with the occupation. In a contemporary world, the need to modernize the traditional design of rickshaws, speed up the roads of Bangladesh, and curtail the physical and financial strain of the rickshaw pullers- are evident. Moreover, it has also proved to be a very important part in the socio-economy of Bangladesh. These fuel-free transports should more convincingly be brought under a massive modernization rather than eradication.

1.5 Project Overview

The key concept of this project is– the Rickshaw-puller will get assistance (rotation) from a motor only when he needs it, and the level of assistance will be ‘according to the need’. A torque-transducer pedal will output the corresponding voltage of torque applied upon pedal by the puller, which will be compared to a predetermined value (the minimum torque). If the applied torque is more than the predetermined value, the motor will be allowed to assist the puller. After crossing this threshold, the more the torque (voltage) is excess to the threshold, the more assistive power will be provided to the puller, proportionately. Certainly, there will be a cut-off; which means that there will also be a maximum value of torque. After that torque, the motor will either not be allowed to assist the puller, or be assisting with its maximum level preset by the designer. These will be done for the safety of the motor and also the driver.

At the beginning of the project, a throttle controlled tricycle electric-rickshaw, currently being seen to ply inside some residential areas of Dhaka was bought for experimentation. This was done in order to avoid mechanical hassle with motor-mounting, battery-installation and most-importantly finding all components together (Brushless motor, controller, batteries) without having to import from abroad, which could be time-consuming and complicated process for non-commercial researchers. The next job was to do the reverse engineering of the existing system to study it properly, because on that system it was intended to implement the technology to make the first prototype. Moreover, no technical information or data sheet was available with any of the components. So, a reverse engineering of the system was necessary.

At the first phase of the project, the system-behaviour was studied thoroughly. Which is the signal that drives the motor, what is the motor-speed characteristic in-response-to that signal, what were the functions of the controller wires, what was the mechanism of other existing features inside the system- were studied.

After a thorough study of the system, at the second phase, a control algorithm was developed to implement the key idea of ‘assistance only when it is needed’. To implement this, the signal from a torque sensor needed to be processed inside another circuit before going to the main controller. (Details about this are explained in following chapters sequentially). The possible circuits were designed and tested. The torque sensor signal was simulated by a variable voltage source for testing the circuits. Finally one design was chosen for implementation on the prototype after analysing the simulation results.

At the final phase of the project, the torque sensor was incorporated with the whole system and tested. Then, after installation of a few necessary accessories (e.g. headlight, indicator, honk etc) and calculating their power-consumption nature, the prototype was brought under a field test where its practical performance was tested and its potential efficiency over other similar electric-rickshaws were approximated using practical data.

1.6 Summary of the Following Chapters

In the second chapter of the paper, the existing electrically improved designs of rickshaw are elucidated; also, the feasibility of the proposed system and the scope for improvement are studied. The third chapter describes the reverse engineering process of the existing model that was bought for experimentations. The development and comparison of control algorithms; and three different techniques for implementing these algorithms are discussed in chapter four. Corresponding to each of these techniques, three extensional circuits were designed and tested; the simulation results were compared and finally a design is chosen for implementation- these are elaborated in chapter five.

Chapter six particularly portrays all the aspects of integrating the torque sensor into the system, starting from managing power source, through mechanical fitting, to testing the whole system’s performance with it in lab conditions. The installed accessories, their circuitry and their power consumption nature are described in chapter seven. The eighth chapter analyzes the performance of the prototype under practical road conditions. Finally, in chapter nine, the paper was concluded highlighting the recharging infrastructure for the system and the scope of future work on this technology.

CHAPTER 2

Overview of Existing Electrical Improvements on Rickshaws

2.1 Introduction

There have been a number of electrical improvement ideas and implementations on the rickshaws in different parts across the globe because of it being a sustainable, fuel-free green transport in the developing parts of the world; especially in South Asian territories. All those concepts share the common idea of reducing the muscular energy implicated by the pullers and provide electrical assistance. In this chapter, three major models which are prototyped and implemented in the sub-continent, two in Bangladesh developed by *Beevatech Limited* and *Boraq Limited*; and the other named "*Soleckshaw*" designed and developed by *Council of Scientific and Industrial Research (CSIR)*, India, will be described along with their major drawbacks and scope for further improvements.

2.2 The *Beevatech* Model of Electric Rickshaw (The PORAG Electric Pedicab)

2.2.1 Overview

Beevatech Limited is the first professional electric auto rickshaw manufacturer in Bangladesh was established in 2001 as a group company of Prime Logistics Ltd. PORAG electric Pedicab Rickshaw eliminated manual labor of Rickshaw pullers and increased their daily income. It is architecturally different from the traditional rickshaws and is manufactured in a steel-body platform showing a 'new-look'. (fig. 2.1).

Fig. 2.1 PORAG Electric Pedicab

The model includes 48V, 500W brushless DC motor drive systems with **throttle position sensor** to control motor speed. That means, the motor drive mechanism is directly controlled by a hand throttle only, and the traditional chain-wheel system, which is though included in the system, is hardly found to be used. The vehicle is seen to be used totally with the motor during almost all the running time. The pullers sometime pedal it after battery discharges. Detail technical specification for this model is described in Chapter 3.

Four 12V 20Ah lead acid batteries were used in the system and battery charging system involved the national power-grid as the main source.

Another model was introduced by Beevatech Limited in 2012 including four 75W solar panels over the rickshaw roof for battery charging with a parallel charging mechanism using the national grid. (fig. 2.2). But, it was proved that the panels were clearly insufficient for charging the batteries to run the 500W motor and it was necessarily charged using the national grid all the time.

Fig. 2.2 PORAG Electric Pedicab with solar panels

2.2.2 Limitations and Scopes of Improvement

- The throttle-control mechanism practically makes the system fully motor-controlled and thus consumes more electrical energy; usually the battery discharges in 5/6 hours of regular running conditions by the rickshaw pullers.
- Reduces the life of the battery and motor due to frequent high-current flow from the battery to the motor.
- The new architecture involves production of new rickshaws and thus, the huge resource of traditional rickshaws already present in the country is still unused; so it is overloading the overloaded rickshaw population.
- The integrated solar-panel of their later model increases the cost of the vehicle for no significant improvement in the power management.

The major scope for development in this model is to develop a mechanism to reduce electrical energy consumption, yet providing comfortable assistance to the rickshaw puller and also limit the use of the motor and protect it from consistent exposure to high current from the batteries.

2.3 The *Boraq* Model of Electric Rickshaw

2.3.1 Overview

Boraq Limited is comparatively a smaller company than Beevatech limited in Bangladesh, yet they came up with some electrical improvements over the rickshaws and managed to overcome some of the limitations of the previously stated model. However, the major feature of this model which was of most importance and relevance to the project is: they 'converted' some old rickshaws to their power-assisted model. They made mechanical modifications in the old rickshaws to accommodate the batteries underneath the seat and mounted the motor identical to the previous one.

Technically, they changed the type of battery used. They introduced a costlier version of lead-acid battery (wet-battery) to extend the run-time. They also used brushed DC motors in some of their products to reduce costs. The control mechanism was still the same—throttle controlled, so its consequences prevailed in the design.

2.3.2Limitations

- The model increased the overall cost for the system drastically, mainly because of the batteries used.
- The system-weight was too much for hybrid operation. It is nearly impossible to pull the vehicle manually without assistance.
- The drawbacks for the throttle-control mechanism still prevailing.

2.4 The *Soleckshaw* in India

2.4.1 Overview

Soleckshaw – a rickshaw powered by solar electric power which was piloted in October, 2008 has been launched as a green postal delivery vehicle in India [20]. Soleckshaw is a battery-powered and pedal assisted dual powered tricycle designed for transportation applications in congested urban areas. Instead of pedaling, soleckshaw will provide some battery support on demand. The batteries are charged at charging stations which are solar powered. That is the only solar connection these rickshaws have. [20] It doesn't yet have a solar panel on top to recharge the battery.

Soleckshaw utilizes a battery exchange design that uses solar-powered recharging stations. This design eliminates the need to place solar panels on the vehicle, thereby reducing weight and cost [21]. The Soleckshaw's technical design involves a 240-350 W brushless DC motor drive [22]. It has a seating capacity of 2-3 passengers and a payload of 150-200 kg, excluding the driver, and will run at a speed of 15 km per hour. Its speed can touch 40 km/hr. [23]. The solar battery, weighing around 15 kg, is placed under the passenger's seat.

2.4.2 Limitations

- It involves a very high initial cost as the system needs to be developed from the scratch [24]; three variants cost: Rs.45000 ($908), Rs. 75000 ($1514), Rs. 85,000 ($1716)
- As this design is also throttle controlled, practically, hybridization of energy is still not satisfactory and the battery discharges in 6-7 hours [20] and requires a full day of charging.
- Most of the rickshaw pullers drafted for the pilot have returned the rickshaws because of technical and financial difficulties. [20] The throttle controlled drive mechanism might be little difficult to learn by the traditional rickshaw pullers.

2.5 Design Challenges for the Proposed System

- To ensure lower energy consumption from the battery by synchronizing the pedaling effort and electrical assistance from the motor.
- To make a cost effective system by using the available rickshaw-resources and performing necessary transformations in the present structure.
- Increase durability of the motor by controlling the frequent constant high current flow through it.
- Ensure the most efficient and effective use of solar energy.

CHAPTER 3

Reverse Engineering of an Existing Model

3.1 Introduction

Reverse engineering is the process of discovering the technological principles of a device, object, or system through analysis of its structure, function, and operation [13]. As mentioned earlier, for implementation of the project an existing model of throttle controlled, battery powered electric rickshaw was bought. Throughout this reverse engineering process, the whole system is analyzed thoroughly in a quantitative point of view. In the following sections, an overview of the model is discussed, with a short description of the components used. One of the major analyses- the speed control mechanism with the throttle, is also conferred. Furthermore, two quantitative experiments has been described to understand the behavior of the entire system; one explaining how the throttle controls the speed of the motor, another explaining the resultant effect on the wheel shaft with pedal (muscular)-power and motor power. The first experiment is necessary to verify the linearity of the throttle input (a voltage signal) and motor speed. It is also necessary to verify if an external voltage works the same way as the throttle does or not. The second experiment was done to understand the mechanical behavior of the system on a combined torque input, i.e. with a combined input force from motor and pedal.

3.2 Overview of the System

The product under research and development was a throttle-controlled fully automatic rickshaw with a modern steel-body and a slightly different architecture. This was a completely motorized vehicle where pedal is only for running on emergency battery-discharges. This particular model of electric rickshaws is introduced in Dhaka by Beevatech Limited- the first professional electric auto rickshaw manufacturer in Bangladesh, established in 2001 as a group company of Prime Logistics Ltd [14]. These products are usually seen plying inside some residential areas of Dhaka city. However, the company is now having difficulties to gain government approval to run legally throughout Dhaka city because of its tremendous level of power consumption from the national grid. That is the reason why the company is now working to make it fully or partially solar powered. However, it will still be very difficult to run the vehicle with solar energy without taking any means to reduce the power it consumes. This is the reason why we are trying to reduce the energy to be drawn from the battery by introducing an hybridization technology which will enable the puller to contribute a portion of power from his body, which will not be either tremendous or close to nothing, but an optimized level.

The manufacturer of this particular model used a different architecture to accommodate the batteries to run the motor which is mounted inside. A brushless DC motor is used, accommodated underneath the vehicle with batteries and controller unit accommodated inside the seat. A detail description will be given in the following section. In short, they used a 48V, 500W, 13.5A, 500rpm rated brushless DC gear motor, a corresponding controller unit, a throttle, a main power-on key, and an emergency ‘motor-stopper’ brake. Four 12V Dry-cell batteries, connected in series, along with the controller were accommodated underneath the passenger seat.

3.3 Components Used

3.3.1 The motor:

A 48V, 500W, 13.5A, 500rpm rated brushless DC gear motor was used in the system. The motor was mounted underneath the seat, attached with the main frame like shown in fig. 3.1.

In a brushless DC motor (BLDC), the rotor has permanent magnets and the stator has an electronically-controlled rotating field, using sensors (rotary encoders or back-EMF) to detect rotor position. As such they have no commutator, and tend to be more efficient and more powerful than commutated motors.

Fig. 3.1Motor mounted under Rickshaw

Brushless motors develop a maximum torque when stationary, linearly decreasing as velocity increases [15]. BLDC motors are most suitable for these kind of vehicles because of their more torque per weight, more torque per watt (increased efficiency), increased reliability, reduced noise, longer lifetime (no brush and commutator erosion), elimination of ionizing sparks from the commutator, and overall reduction of electromagnetic interference (EMI) [16].

3.3.2 The Controller Box

Brushless motors need complicated electronics. The manufacturer integrated all the electronics into a black box. But due to the unavailability of proper data-sheet, the controller wires were identified using some online resources, experiments, and exploring the connections in the system. The identification diagram is in fig. 3.2

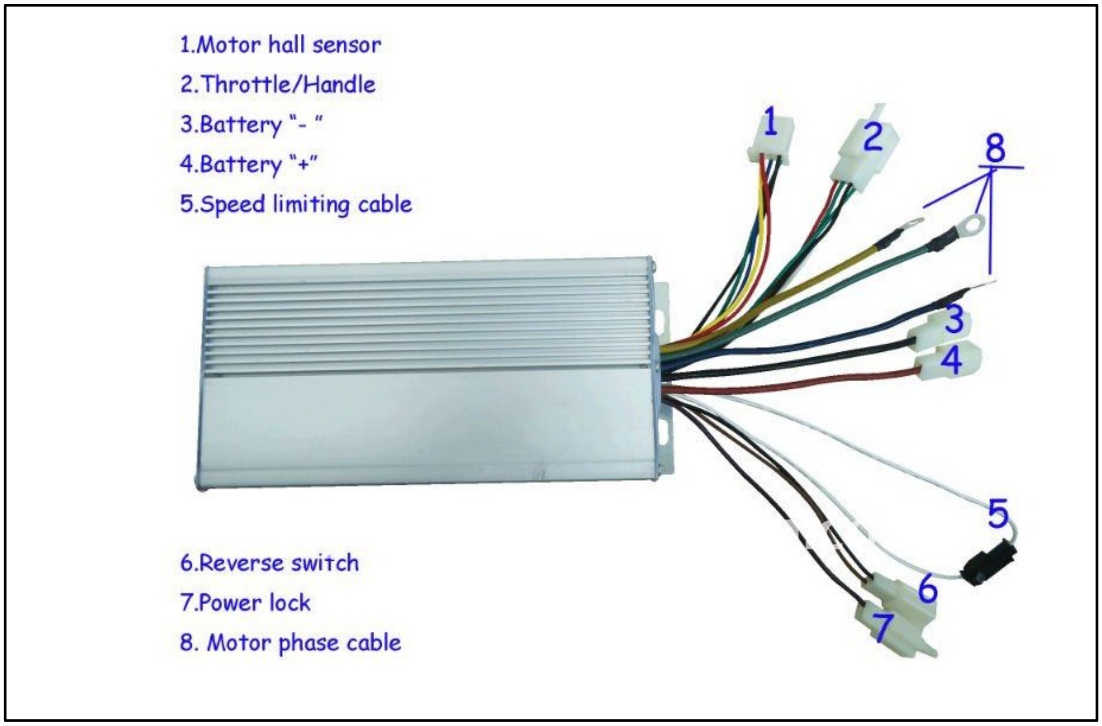

Fig.3.2Identification of the controller cables, source:[12]

3.3.3 The Batteries

Four 12V, 20Ah Rechargeable batteries were used in series to provide 48 Volts to the BLDC motor. These were lead-acid batteries each weighing 7.1 kgs and 181 X 77 X 171 mm in dimension. The batteries were accommodated inside the seats.

With full charge each battery shows 12.9 volts across their terminals and 51.6 volts after series combination.

Fig.3.3 Batteries accommodated inside the seat

3.3.4. The Throttle Position Sensor (TPS)

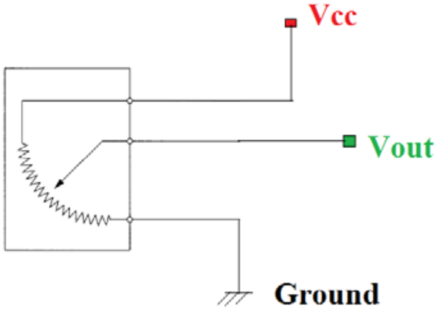

Fig. 3.4 Diagram for a Throttle Position Sensor (TPS)

A throttle was used to control the speed of the motor. Throttles are generally used in all kinds of e-bikes to control the motor speed. BLDC motor controllers are designed in such a way that a voltage signal (usually not more than 5V) controls the minimum to maximum speed of the motor. A throttle is a specially designed potentiometer where a specific V_{cc} (biasing voltage) is provided from the main controller unit and outputs voltage corresponding to angle of the throttle, which is supplied to the controller where it is processed to deliver corresponding speed by the motor. The circuit diagram of a throttle position sensor (TPS) is given in fig.3.4, and the throttle position, along with the hand-clutch and power-key (to be described later) is given in fig. 3.5. In the following sections the behavior of the motor corresponding to the voltage signal provided by the TPS will be described in details.

3.3.5. The Hand-Clutch and Power-Key

A power key is used in the system to turn the whole system ‘on’ or ‘off’ manually. This is basically a mechanism to ‘short’ two wires that go directly to the controller unit when the system is keyed. The hand-clutch is mounted on the left handle of the rickshaw, along with the traditional front-wheel brake-system. It is used to stop the motor at-once when needed, usually in case of an emergency. The hand clutch will stop the motor irrespective of the throttle position as long as it is held like a brake. It will start the motor from the corresponding throttle position the moment it is left to its original position.

Fig. 3.5 Position of the Hand-Clutch, power-key, and throttle.

Fig. 3.6 shows the connections of the motor wires with the controller, TPS, and power-key. The hall-sensors of the BLDC motors and the motor phase cables are also connected in the diagram.

3.3.6. Speed Limiting Cable

There are two Speed Limiting Cables coming out of the CU which were connected by default. The speed of the motor increases significantly if the wires are 'opened'. The open conditions were not used throughout the system design as the speed becomes very high and the system becomes unstable for experimentation.

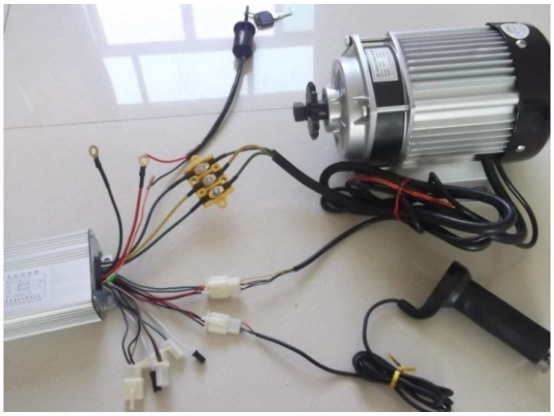

Fig.3.6 Components assembled separately, source: [11]

3.4 Speed Control Mechanism of the Existing System

In this system, the speed of the motor is controlled by the Throttle Position Sensor (TPS) unit. The TPS unit supplies corresponding throttle position voltage to the main BLDC motor controller unit. The quantitative analysis of this fact will be discussed in the following section. The idea is self explanatory from figure 3.7. The main power supply is the 48 V Battery which powers the motor and the controller unit. The CU provides necessary biasing to the TPS and the TPS outputs voltages according to the throttle's angle. This output is fed to the C.U. which then coerces the motor.

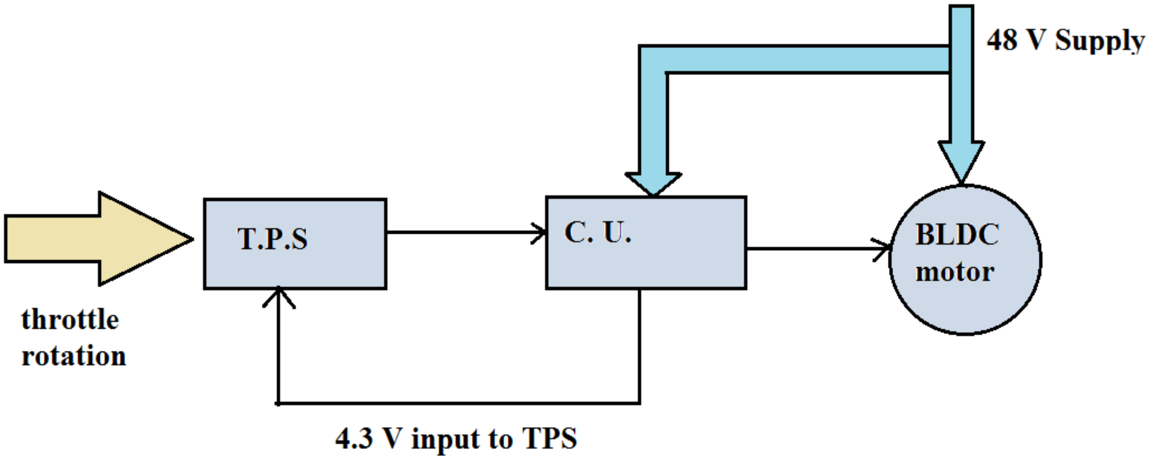

Fig. 3.7 Block diagram of the existing system.

3.5 The throttle terminals

In the system, a throttle was controlling the speed of the motor. Hence, it was the characteristics of throttle terminals in the controller which was of interest. It was experimentally found that the throttle might be acting as a potentiometer and providing voltage according to rotation. Among the three terminals that went to the CU (Red, Green, and Black); between red and black, the voltage was always 4.3V; between Green and Black wires the voltage (output) varied from 0.82 to 3.3V- varying the speed of the motor.The throttle cable was removed and similar voltage was supplied by an external voltage source, and the results were found to be similar.

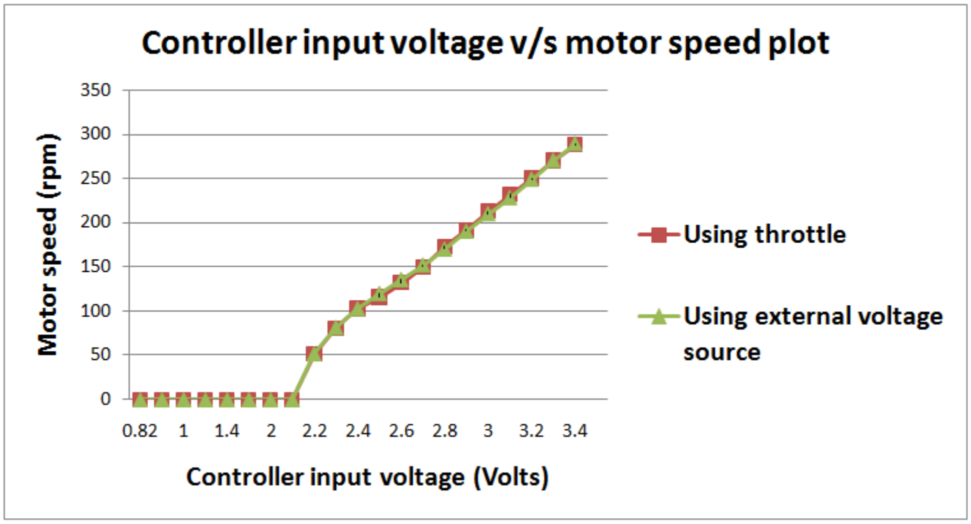

Fig. 3.8 controller input voltage v/s motor speed plot

If we analyze the plot of fig. 3.8, we can see that there is a predefined threshold voltage already existing in the present system, which is 2.2V. Before reaching 2.2V, the motor never starts; and after 2.2V, the motor speed increases almost linearly. Data were taken up-to 3.4 volts as this was the maximum throttle voltage. However, the speed could be further increased using external battery but the system tends to become quite unstable after 3.6/3.7 volts across the terminal. It is concluded from the experiment that the motor speed is almost linear to the controller input voltage, which presently comes from the throttle. The target is to provide ‘similar’ pattern of voltage using a torque sensor which will correspond to the “demand” of motor assistance. This profile was most helpful for designing the main control mechanism. This will be further explained in later chapters.

3.6The shaft speed

The experiment was done in order to understand the nature of the shaft speed corresponding to manual pedalling and motor speed. A sample pedalling speed was introduced into experiment, ranging from 150-200rpm. Though the wheels were not connected in the lab-setup, it was hard to maintain a stable speed manually; however a speed of 150-200 rpm was achieved. The motor speed characteristics with-respect-to controller input voltageswere found in the preceding experiment. The total speed of the shaft (motor + manual) was recorded with respect to different input voltages. It was found that the shaft rotated at the "higher speed" between the motor and manual input. That means the higher speed at any instance is followed as the total speed. (Fig. 3.9) In the experiment from 2.2-2.7V, the manual speed sustains (however, it feels easier to pedal after 2.2V) up to 2.7V for the current state of pedal speed, and after 2.7V, the motor speed is followed.

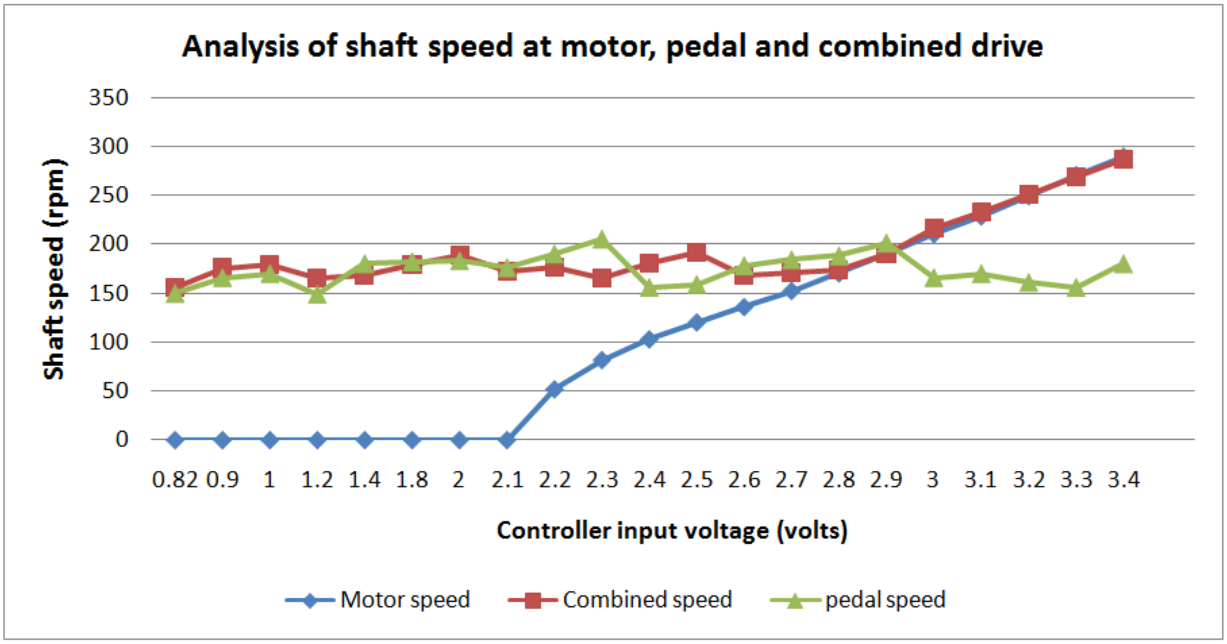

Fig. 3.9 Analysis of resultant speed at combined forces

From this experiment, it could be concluded that the assistance that comes from the motor comes in-terms-of torque, not speed. That means the speed (rpm) is not added up when both driving forces (motor and pedal) are active simultaneously. However, the higher speed is maintained, and the assistance comes in the form of 'easiness', that means in-terms-of torque to be applied. In fig. 3.9, from 2.2 to 2.8 V, the motor is running but the total shaft speed is tending to follow the pedal speed as it is higher. After the break-even point of 2.8 V, the shaft speed follows the motor speed.

CHAPTER 4

The Control Algorithm and Application

4.1 Introduction

The desired motor driver system- which provides motor assistance only when required by the user; through measuring the input torque on the pedal, with as minor external modifications as possible, was to be implemented using the existing features of the machine. However, a deep understanding of the system was necessary in order to comply with the project's objective and the present system we were working on. Also, the first prototype was built on the platform of the present model. The following sections describe the control algorithm of the system and the key observations that played significant role in the circuit design.Furthermore, the possible circuit designs and reasoning for choosing the selected design are discussed.

4.2 The Control Algorithm

The main idea of motor control for this project is to control the speed of the BLDC motor with an external signal from a torque sensor. There must be a minimum amount of torque (Threshold Torque) which when applied, should run the motor. If the torque sensor output voltage is V_s, and the sensor's voltage output for Threshold Torque is V_{th}, then as soon as V_s exceeds V_{th}, the motor speed should increase proportionately with respect to the voltage that is excess from V_{th}. At the same time, overuse of the motor must be restricted, which means the motor cannot be allowed to run at very high speed. If V_s somehow controls the motor speed, a system has to be developed so that either:

1) Stops the motor or resets the system after V_s crossing a specified voltage; Or
2) Limits V_s to a maximum level even the torque input corresponds to a higher voltage.

If V_{in} goes to C.U as the input signal that controls the motor speed and $V_{in} = K \times V_s$; where K is a constant indicating the level of ease for the system, and V_{max} is a preset value of ($K\times V_s$) that corresponds to a maximum limit of V_{in}, then the algorithm is can be set through either of the two following approaches:

# OPTION 1	# OPTION 2
Get V_s $V_{in} = K\times Vs$ *If* $V_{in} \geq K\times V_{th}$ *&&* $V_{in} < V_{max}$ *Motor speed =* $M * (V_{in} - 2.2)$ *Else, Motor speed = 0* *% M is constant* ***Go to** : Get* V_s	*Get Vs* $V_{in} = K\times V_s$ *% Amplifier designed so that maximum output is* V_{max} *If* $V_{in} \geq K\times V_{th}$ *Motor speed =* $M\times(V_{in}-2.2)$*; % M is constant* *Else,Motor speed = 0* ***Go to :** Get* V_s

Both the algorithms are designed and simulated with a voltage source (assuming the voltage is coming from a sensor) before going for finalizing the design for the system. Three designs will be proposed in this paper throughout and the key problems and advantages will be highlighted. The used algorithm and circuit design will be chosen on the basis of an optimized assistance level, and lack of complicacy. Those will be described in detail in the following chapters.

4.3 Key Observations from the System and Possible Solutions for Implementation of the Idea

As explained in the previous chapter, the Controller Unit (CU) has an input terminal that comes from the throttle position sensor (TPS). This provides voltage signal which controls the speed of the motor almost linearly with increasing voltage that is access to its predefined threshold (2.2V). The key idea is to provide this voltage externally, from a torque sensor which outputs voltage signal proportionately with increasing torque. However, the motor should not start at literally any torque. There should be a minimum amount of torque (threshold) that must be applied in order to get motor assistance. That means the motor speed should be proportional to the output voltage of Torque Sensor (TS) that is access to the minimum voltage. **So, the built-in threshold should correspond to the desired threshold torque output.**

The main idea, as described before, was that the motor will assist the puller according to the torque he applies on the pedal. There will be two predefined set-points:

1) A minimum torque at which puller starts getting assistance from motor, *A*N-m.
2) A maximum torque after which the puller will not get any assistance.

Let, the corresponding voltage for *A* N-m be **X** Volts.

$$\mathbf{2.2 = K \times X} \qquad \mathbf{(1)}$$

Where, K is a constant gain factor, which will be defined by the circuit designer as a determinant of *‘level of ease’*. If, after amplification, the torque represents 2.2V, the motor will start running, and the speed will increase with increasing input torque, as torque corresponds to voltage now. The gain should be such that the minimum torque we set corresponds to 2.2V.

Now, it’s not necessary that the upper cut-off voltage has to be corresponding to any torque; we can set that value according to motor-stability limit. For example, we can set the value as 3.5V as the system tends to be unstable beyond that voltage with very high speed.

Hence, whenever the controller will get more than or equal to 2.2V at the throttle terminals (controller input voltage), it will start running and increase speed linearly, irrespective of from where it is getting that voltage. **The sensor voltage has to be manipulated in such a way that for the controller, it will seem that the signal is coming directly from the throttle, but practically it will be serving the purpose of processing the voltage signal from the torque sensor.**

The external hardware that is to be designed has to have two distinct parts. The first part is an amplifier which transforms the minimum torque to 2.2V. The value of the amplifier gain will depend on sensor characteristics and the value of minimum torque we decide. The output of the amplifier will straightaway be connected to the controller input terminals. But, the amplifier output will always be compared to the cut-off voltage (the voltage at which the motor is to be stopped). The comparator will output a ‘high’ whenever the voltage exceeds the cut-off (in this case, 3.5V). Now, with the high output, the motor can be stopped in two ways:

1) **Short** the hand-clutch wires(the wires that are shorted by a clutch to stop the motor suddenly) with an electronic switch; or
2) **Open** the main power key wires (the wires that are shorted in order to start the whole system) with an electronic switch

But, there is a difference between these two methods of stopping the motor. If the motor is stopped by the hand-clutch, after crossing the upper-limit-voltage, when the voltage gradually comes down, as-soon-as it goes below the upper-limit, (i.e. in the operating range) it starts running at the corresponding high-speed (as in fig. 3.8); this could be fatal in a running vehicle as the puller will feel a sudden 'thrust' which will be duly unwanted in a vehicle running smoothly with its inertia. These facts are highlighted in details in the next chapter describing the simulation of the sensor with a voltage source to test the circuitry.

If the motor is stopped by the second above mentioned method, the problem does not sustain. Because, it has been tested that once the motor is stopped with the **main power-key**, even if the voltage "comes down" to the operating range, the motor does not run; **the voltage has to go down again to the minimum and then "come back" and cross the threshold to start the motor**. This was a very useful finding for keeping the external control circuit very simple. The drawback of this procedure is that there is always a current flow through the external circuit to keep the switch 'on' most of the time, as we have to "open" the wires to stop the motor.

However, there is another way of limiting the speed of the motor- by limiting the maximum output voltage of the amplifier to a reasonable value (say 3.5V) using a reduced biasing voltage. For example, if we use LM358 Operational Amplifier IC, and provide a biasing voltage of +5V, the maximum output voltage will be 3.5V. There are several advantages of using LM358 Operational Amplifier. They are:

1) Negative biasing voltage is not required, reduces power supply complications.

2) Large operating range; can be used with the same biasing voltage as the torque sensor (+5V) and hence, only one power bus can be used.
3) Reduces Complicacy of circuits to a great extent.

For building the first prototype, the second algorithm with the third application technique will be used. That means the amplifier will be designed to provide an output voltage no more than a preset amount and no comparator will be used. This design is neither risky, nor "too much" energy-saving. This design optimizes battery, circuit complication and manual labour perfectly. The fact is analyzed quantitatively in the following chapter.

4.4 Block-Diagram of the External Circuits

4.4.1 Block diagram of Design Proposal – I

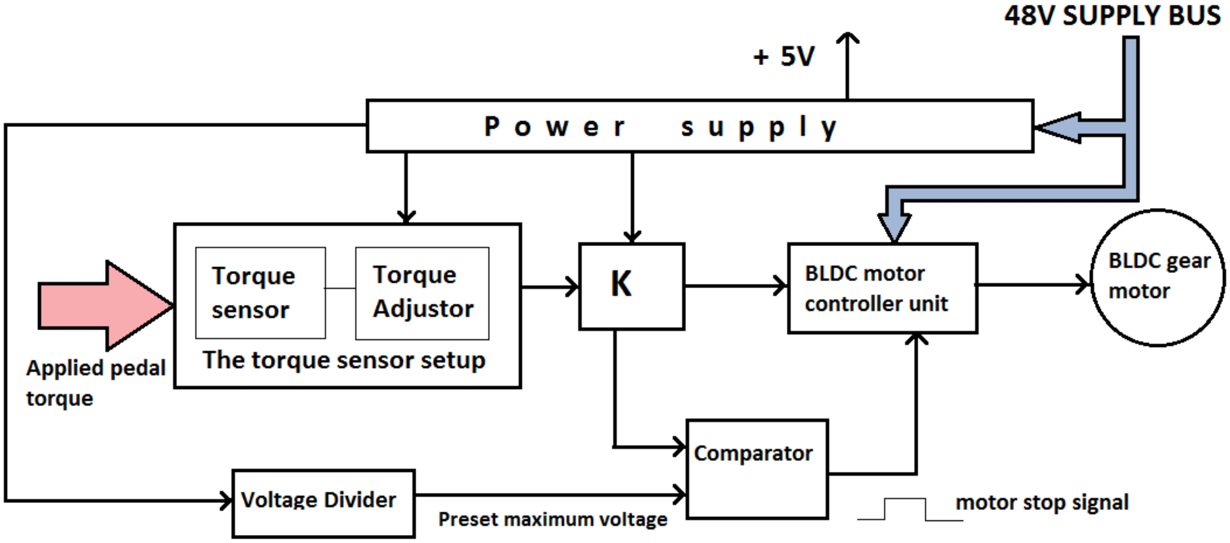

Fig. 4.1 Block diagram of design proposal – I

In this design, as depicted in fig. 4.1 The applied torque passes through the torque sensor setup and gets amplified by the "K" block. After amplification the signal feeds directly to the Controller Input Terminals (CIT). At the same time the amplified signal is compared with the maximum torque corresponding amplified voltage (the voltage over which should not be fed to the CIT). If the output of K-Block is higher than the preset maximum voltage, the comparator sends a "HIGH" signal to the controller unit, which stops the motor as long as it is high.

This signal can stop the motor in two ways, like explained before; by shorting the hand-clutch wires, or by opening the power-key wires. Two of these sub-methods have different consequences; these will be explained in the next chapter when sensor simulation results will be presented for different models.

In this design, the 48V power supply is the only source of power which directly powers the motor and the C.U. A 5V regulator from one of its 12V batteries can power the torque sensor, amplifier and comparator. A voltage divider from the 5V bus can be used to reduce the voltage and set to the cutoff voltage feeding the comparator for comparison.

4.4.2 Block diagram of Design Proposal – II

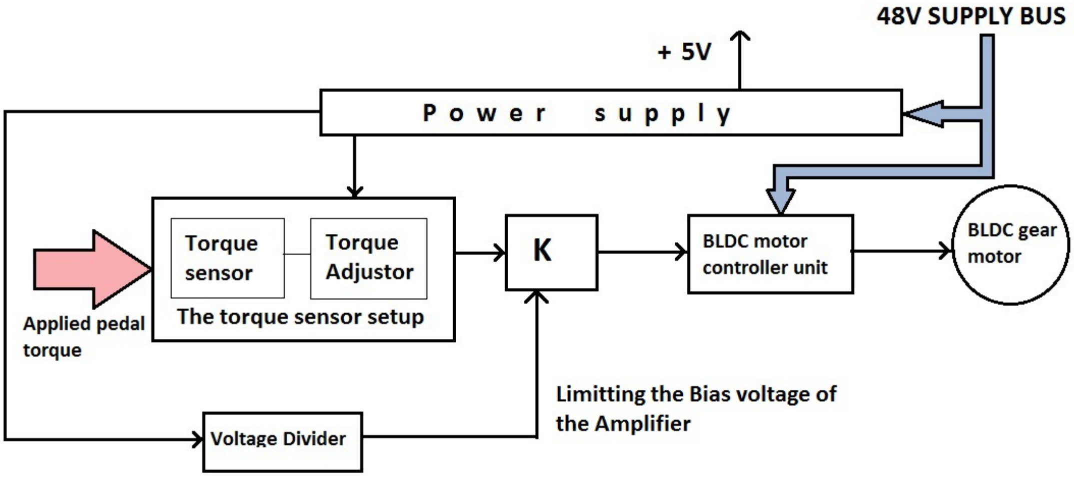

Fig. 4.2 Block diagram of Design Proposal – II

In this design, a different technique is used to limit the controller input voltage to a certain point. Here, no switching of motor is required, but a continuous process takes place where the output of the amplifier that goes directly to the controller input terminals (between green and black terminals) is limited by a certain value by using a controlled biasing voltage for the amplifier.

In figure 4.2 it can be seen that, the amplifier block 'K' is not powered from a secondary 5V power supply (or any other step-down value), but from a lower divided voltage using a voltage divider. The value of the reduced voltage will depend on the particular Op-Amp used and its maximum output voltage in 5V biasing. For example, if we want to limit the voltage to 3.0 V, the biasing voltage will be set accordingly. For an LM358 Operational Amplifier IC, a 5V biasing leads to a maximum voltage of 3.5V, and its operating range is 3V-32V.

4.5 Conclusion

Further, both of these two proposals with three different circuit designs are implemented and tested using a simulation torque sensor signal (voltage source assuming to be giving output from T.S.), and are described in the following chapter. The best design will be chosen considering the simulation results and optimization factors.

CHAPTER 5

Testing the External Circuits: Simulating the Torque Sensor Signal

5.1 Introduction

According to the two major design proposals in the previous chapter (with two sub-methods for the first), three external circuits were designed and implemented for testing. In this chapter, all three designs will be described along with the advantages and drawbacks of each. In conclusion, a final decision will be presented for implementation in the prototype.

5.2 Design- I:

5.2.1. Introduction:

The main objective of design-I is to use the circuit to limit the use of motor (stopping it) by **shorting the hand-clutch wires**. This design uses an amplifier to process and control the sensor signal at the first place to bring it in the operating region to work smoothly with the system. The output of the sensor goes directly to the controller unit's (CU) signal-input terminals. But at the same time the signal is compared with a comparator with a preset voltage. Preset voltage is that amount of voltage where we want our motor to stop assisting and limit the use of motor for its safety. When the amplifier output (which is fed to the CU) is greater than the preset voltage, the comparator will output 'high' which will short the hand clutch wires instantly through a MOSFET switch.

5.2.2. The Circuit-Diagram and Explanation:

Fig. 5.1 shows the circuit diagram for design-I. We can see that the sensor signal will go to the amplifier input at the first place. The amplifier output goes directly to the CU-input. The gain of this amplifier will act as the determinant of 'level-of-ease' for the system. This even works as a 'torque adjustor' which may be kept variable for the system.

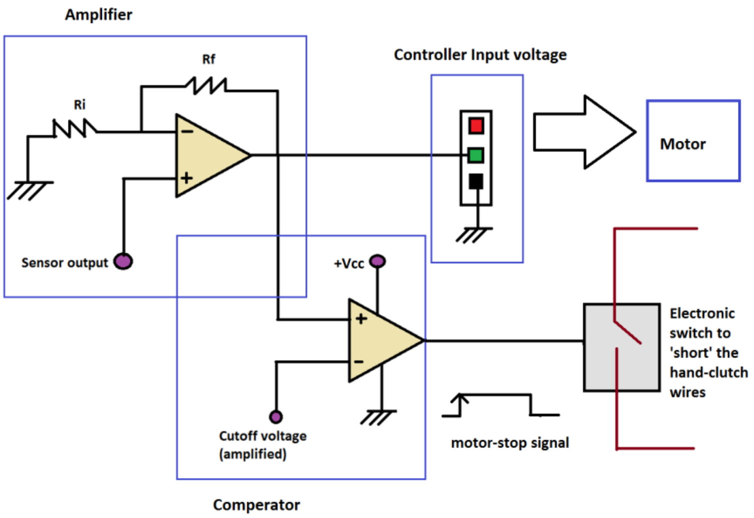

Fig. 5.1 Circuit Diagram for Design-I

The value of R_f will be adjusted according to the desired level of ease we would like to provide the pullers for running on road. This value will also depend on the torque-voltage characteristics of the torque sensor involved with the system. However, for testing it without the sensor, the gain is set to unity and all voltage connections (power for biasing) are given from external voltage sources. Also, the input signal is given from another source assuming it to be coming from the sensor.

The cut-off voltage is supplied in the negative (-) input of another op-amp and the positive is connected to the amplifier output for constant monitoring. Whenever the output goes above cut-off (say 3.5V), the motor stop signal stops the motor by shorting the hand-clutch wires with a MOSFET switch.

5.2.3. Sensor Simulation and Results:

For simulation, the gain was set to 1; the cut-off voltage was set to 3.5V. The system behaviour with these settings can be visualized with fig. 5.2 below.

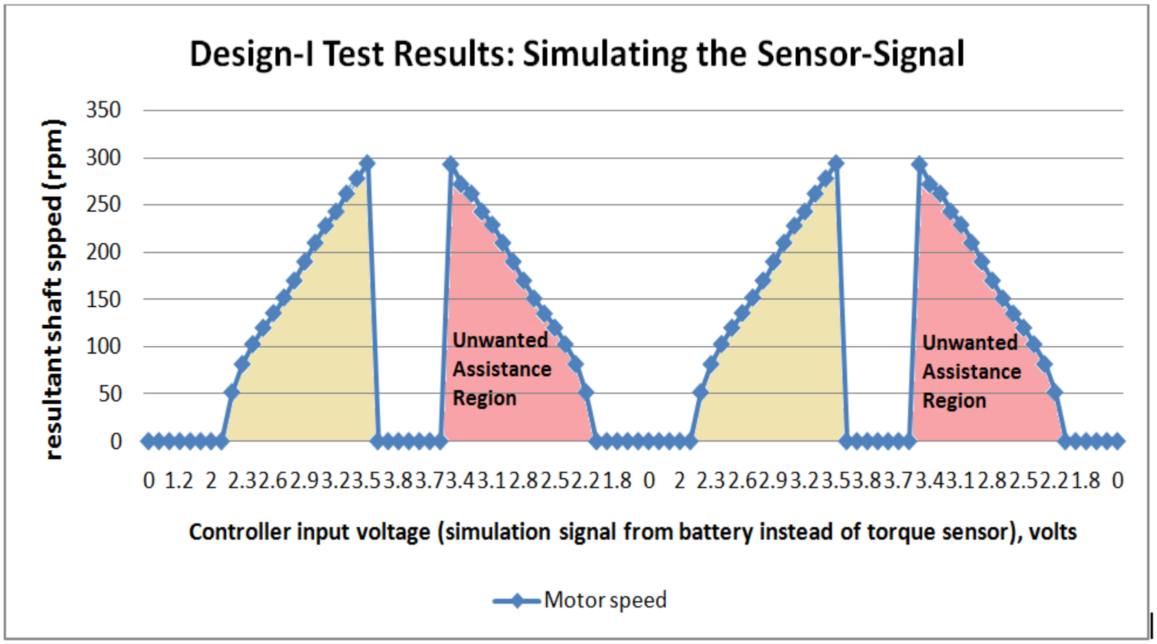

Fig. 5.2 Design-I simulation results

For simulation, voltage signals were provided following the pattern of 0 V to 4.0 V in constant intervals; then 4.0V-to 0V; and repeated once.

5.2.4. Sensor Simulation Data:

Input Voltage	Motor RPM		Input Voltage	Motor RPM
0	0		1	0
0.5	0		0	0
1	0		1	0
1.2	0		1.5	0
1.4	0		2	0
1.8	0		2.1	0
2	0		2.2	51.8
2.1	0		2.3	81.5
2.2	51.8		2.4	102.7
2.3	81.5		2.5	120
2.4	102.7		2.6	135.6
2.5	120		2.7	152

2.6	135.6		2.8	170
2.7	152		2.9	190
2.8	170		3	210
2.9	190		3.1	228
3	210		3.2	243
3.1	228		3.3	262
3.2	243		3.4	278
3.3	262		3.5	294
3.4	278		3.6	0
3.5	294		3.7	0
3.6	0		3.8	0
3.7	0		4	0
3.8	0		3.8	0
4	0		3.7	0
3.8	0		3.6	0
3.7	0		3.5	293
3.6	0		3.4	272
3.5	293		3.3	262
3.4	272		3.2	243
3.3	262		3.1	229
3.2	243		3	210
3.1	229		2.9	190
3	210		2.8	170
2.9	190		2.7	151
2.8	170		2.6	135
2.7	151		2.5	120
2.6	135		2.4	102.5
2.5	120		2.3	81.5
2.4	102.5		2.2	51.8
2.3	81.5		2.1	0

2.2	51.8		2	0
2.1	0		1.8	0
2	0		1.4	0
1.8	0		1	0
1.4	0		0	0

Table 5.1: Simulation Data for Design-I

5.2.5. Comments:

The design has one benefit; it is easy to implement as it is easy to use a MOSFET switch to short the hand-clutch wires and these wires are independent of the motor's main power and used as an emergency motor stopper.

There are few drawbacks of this design:

1) The motor speed increases linearly as voltage increases as expected. After the input crosses 3.5V the motor stops also as expected. But, when it again comes down from a higher value and crosses the cut-off (3.5V) **from above**, the motor-stop signal becomes 'low'; so the motor starts to rotate at the corresponding voltages (3.5, 3.4, 3.3 etc), which may be fatal in some cases. We can call it an "unwanted assistance"—because, after a high torque when the pedal is released, a falling voltage might cause a sudden 'thrust' to the puller, which might make him uncomfortable to ride in. **This phenomenon leads to discontinuity in the whole assistive-system.**
2) It might be a complicated task to power the electronics of the circuit from the main source of power, i.e. The Rickshaw battery. The negative biasing might also be a problematic task. Though solvable, a smarter solution is expected.

5.3 Design- II:

5.3.1. Introduction:

The main objective of design-II is to use the circuit to limit the use of motor (stopping it) by **opening the power-key wires**. This design uses an amplifier to process and control the sensor signal at the first place to bring it in the operating region, identical to the previous design. The output of the sensor goes directly to the controller unit's (CU) signal-input terminals. But at the same time the signal is compared with a comparator with a preset voltage like before. When the amplifier output (which is fed to the CU) is greater than the preset voltage, the comparator will output 'LOW' which will 'open' the power-key wires instantly through a MOSFET switch. This time a LOW signal stops the motor.

5.3.2. The Circuit-Diagram and Explanation:

The architecture of design-II is almost identical to that of Design-I. The key difference is, as mentioned before, it opens the power-key wires than shorting the hand-clutch ones. The cut-off voltage is supplied in the positive (+) input of another op-amp and the negative is connected to the amplifier output for constant monitoring. Whenever the output goes above cut-off (say 3.5V), the motor stop signal stops the motor by opening the power-key-wires with LOW signal in the MOSFET switch.

In this design, a LOW signal stops the motor. Most of the time of operation, the comparator output is HIGH acting as a secondary "series" switch for the power key. The signal must be high power motor operation.

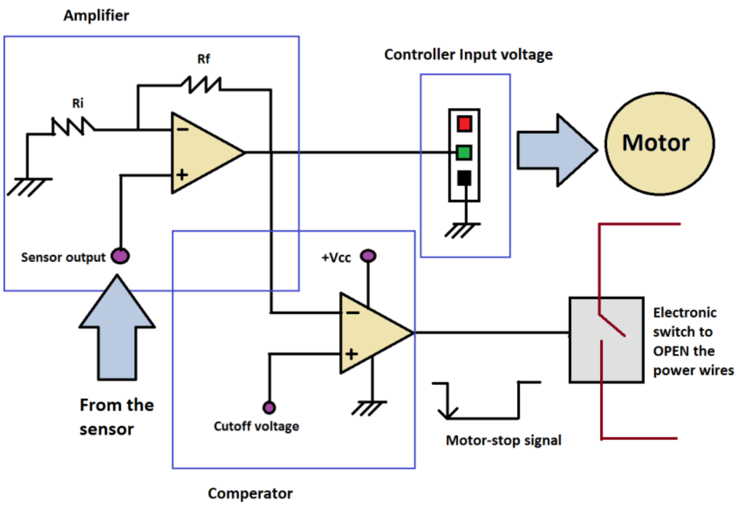

Fig. 5.3 Circuit Diagram for Design-II

5.3.3. Sensor Simulation and Results:

For simulation, the gain was set to 1; the cut-off voltage was set to 3.5V. The system behaviour with these settings can be visualized with fig. 5.4 below.

For simulation, voltage signals were provided following the pattern of 0 V to 4.0 V in constant intervals; then 4.0V-to 0V; and repeated once; as identical as the previous experiment.

As illustrated in fig. 5.4, we observe that, increasing torque (voltage) is causing proportionately increasing motor assistance. After the cut-off, the motor stops immediately and does not start again unless the voltage crosses the threshold from below. Unwanted assistance was avoided here.

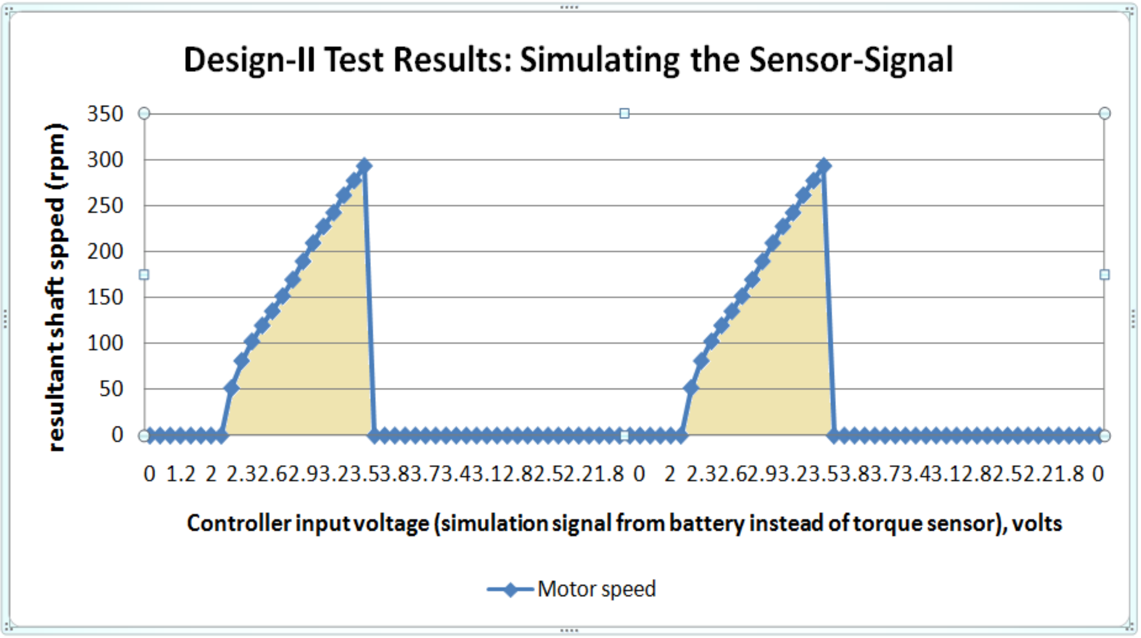

Fig. 5.4 Design-II simulation results

5.3.4. Simulation Data:

Input Voltage	Motor RPM		Input Voltage	Motor RPM
0	0		1	0
0.5	0		0	0
1	0		1	0
1.2	0		1.5	0
1.4	0		2	0
1.8	0		2.1	0
2	0		2.2	51.8
2.1	0		2.3	81.5
2.2	51.8		2.4	102.7
2.3	81.5		2.5	120
2.4	102.7		2.6	135.6
2.5	120		2.7	152
2.6	135.6		2.8	170
2.7	152		2.9	190

2.8	170		3	210
2.9	190		3.1	228
3	210		3.2	243
3.1	228		3.3	262
3.2	243		3.4	278
3.3	262		3.5	294
3.4	278		3.6	0
3.5	294		3.7	0
3.6	0		3.8	0
3.7	0		4	0
3.8	0		3.8	0
4	0		3.7	0
3.8	0		3.6	0
3.7	0		3.5	0
3.6	0		3.4	0
3.5	0		3.3	0
3.4	0		3.2	0
3.3	0		3.1	0
3.2	0		3	0
3.1	0		2.9	0
3	0		2.8	0
2.9	0		2.7	0
2.8	0		2.6	0
2.7	0		2.5	0
2.6	0		2.4	0
2.5	0		2.3	0
2.4	0		2.2	0
2.3	0		2.1	0
2.2	0		2	0
2.1	0		1.8	0

2	0		1.4	0
1.8	0		1	0
1.4	0		0	0

Table 5.2 : Simulation Data for Design-II

5.3.5. Comments:

The design has two benefits:

1) It diminishes the problem with the ‘unwanted assistance’ from the last design;
2) It is the most electrical-energy-saving design as it provides least possible assistance from the motor.

The major drawbacks of the design are:

1) Motor will be assisting the puller for a very short period of time. Consistent high-assistance at any time-duration might not be possible, e.g. going uphill, when torque will be high and consistent.
2) Rickshaw pullers might not feel satisfied with this amount of assistance.
3) Frequent motor-switching will take place; discontinuity in electrical assistance still prevails.
4) The external circuit will lose its independency as it will have to be associated with the power-key; the power-key will as-a-result become a series of two switches, which might be problematic for further maintenance and trouble-shooting of the system.
5) A MOSFET will have to be ‘always on’ to provide the electrical connection for motor during assistance region; current will be drawn from the battery.

Both of these designs can practically be implemented as the torque sensor signal will not necessarily be following the simulation pattern but expected to be random. However, a better consistent design is desired for an optimized performance both in-terms-of ease and power-consumption.

5.4 Design- III:

5.4.1. Introduction:

This design uses a different technique to limit the use of the motor. The basic concept used in this design is to limit the output of an op-amp by limiting its biasing voltage. We know that for a specific level of biasing voltage, the output of an op-amp is maximized to a value depending on that voltage. In this design, LM358 operational amplifier will be used with a biasing of +5V to limit the output to 3.5V and the output will be directly fed in the CU terminals.

5.4.2. The Circuit-Diagram and Explanation:

Fig. 5.5 illustrates the idea of design-III system. It uses LM358 op-amp as the key device. The LM358 consists of two independent, high gain;internally frequency compensated operational amplifierswhich were designed specifically to operate from a singlepower supply over a wide range of voltages. Operation fromsplit power supplies is also possible and the low power supplycurrent drain is independent of the magnitude of thepower supply voltage. [17].

With a supply voltage of +5V, the amplifier’s maximum output voltage is 3.5V. This characteristic will help the system to maintain a maximum tolerable voltage input to the CU without interrupting the whole system by motor switching or sudden-stop-runs.

For example, if the gain is set to 2, an input of 1.5V will give 3V; but an input of 2V will not give 4V as output, but will show 3.5V. We will take the advantage of this in the circuit design.

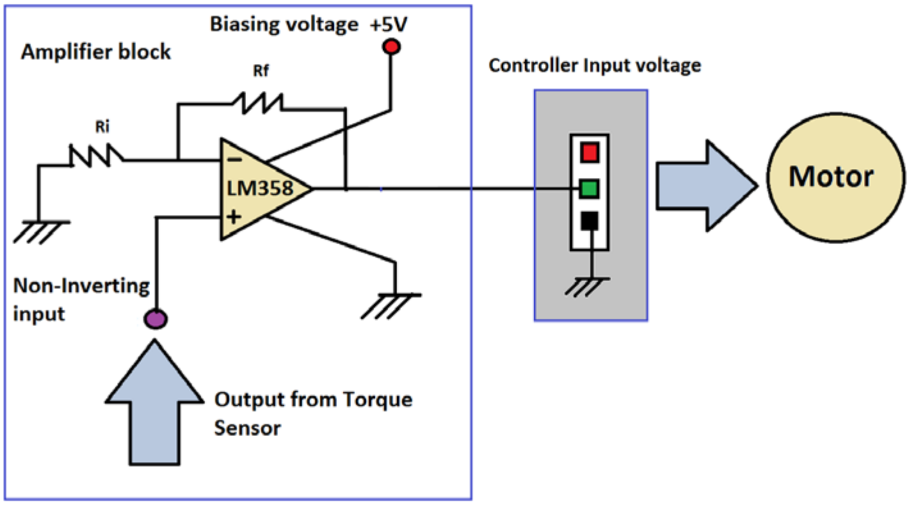

Fig. 5.5 Circuit Diagram for Design-III

5.4.3. Simulation and Results:

For simulation, the gain was set to 1; the biasing voltage was set to 5V. The system behaviour with these settings can be visualized with fig. 5.6 below.

For simulation, voltage signals were provided following the pattern of 0 V to 4.0 V in constant intervals; then 4.0V-to 0V; and repeated once; as identical as the previous experiments.

As illustrated in fig. 5.6, we observe that, increasing torque (voltage) is causing proportionately increasing motor assistance. After the cut-off, the motor continues to run in the maximum possible voltage that is 3.5 here. Again, when the voltage starts to drop, the speed starts to drop accordingly with the regular fashion. Discontinuity of assistance is properly avoided in this design. The region of assistance is also increased.

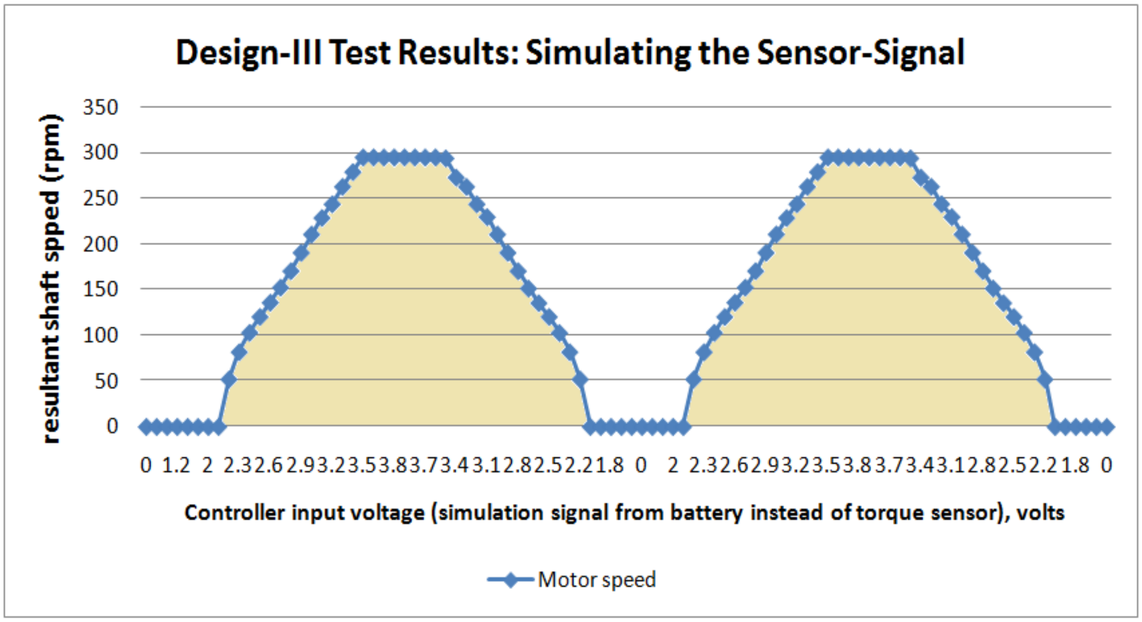

Fig. 5.6 Design-III simulation results

5.4.4. Sensor Simulation Data:

Input Voltage	Motor RPM		Input Voltage	Motor RPM
0	0		1	0
0.5	0		0	0
1	0		1	0
1.2	0		1.5	0
1.4	0		2	0
1.8	0		2.1	0
2	0		2.2	51.8
2.1	0		2.3	81.5
2.2	51.8		2.4	102.7
2.3	81.5		2.5	120
2.4	102.7		2.6	135.6
2.5	120		2.7	152
2.6	135.6		2.8	170
2.7	152		2.9	190
2.8	170		3	210

2.9	190		3.1	228
3	210		3.2	243
3.1	228		3.3	262
3.2	243		3.4	278
3.3	262		3.5	294
3.4	278		3.6	294
3.5	294		3.7	294
3.6	294		3.8	294
3.7	294		4	294
3.8	294		3.8	294
4	294		3.7	294
3.8	294		3.6	294
3.7	294		3.5	293
3.6	294		3.4	272
3.5	293		3.3	262
3.4	272		3.2	243
3.3	262		3.1	229
3.2	243		3	210
3.1	229		2.9	190
3	210		2.8	170
2.9	190		2.7	151
2.8	170		2.6	135
2.7	151		2.5	120
2.6	135		2.4	102.5
2.5	120		2.3	81.5
2.4	102.5		2.2	51.8
2.3	81.5		2.1	0
2.2	51.8		2	0
2.1	0		1.8	0
2	0		1.4	0

1.8	0		1	0
1.4	0		0	0

Table 5.3 : Simulation Data for Design-III

5.4.5. Comments:

This design adds some very important benefits to the system and diminishes most of the flaws of the previous designs. These are:

1) The external circuit becomes independent of hand-clutch or power-keys, as the mechanism for limiting the motor’s use is integrated in the electronics, i.e. the maximum output for op-amp is limited by limiting the biasing voltage.
2) Reduces complicacy of electronics significantly. The circuit will consist of only voltage regulator circuit and op-amp IC.
3) Torque sensor and all other devices can be biased using a single supply of 5V. Power supply complications are eradicated.
4) Negative biasing is not required forLM358.
5) Maintains the continuity of assistance in this hybrid vehicle. No sudden drop of rpm will take place. Motor will assist the user whenever required, according to requirement, within its limit. When more assistance is required, it will not stop assisting, but will continue to assist with its maximum limit.
6) No sudden thrust takes place during riding conditions; the ride will be comfortable.
7) It becomes easy to power all devices from the main vehicle battery using 7805 voltage regulator (to be explained in later chapters).
8) Optimization of manual power and electric power can be achieved.
9) Consistent high-assistance can be achieved when required; for example, **while going uphill**, the torque will frequently cross maximum level, but at that time, of the motor stops assisting, it might be fatal. So, even after crossing the maximum torque level, the motor will not “stop responding”, but will be assisting with its maximum power corresponding to 3.5V.
10) No frequent motor-switching takes place.

5.5 Selection of External Circuit -- Counter Arguments

5.5.1 Selection of the External Circuit

Based on the facts explained in 5.4.5, **Design-III** was selected for final implementation with the system. A few arguments against this system will be defended in this section.

1) ***"It will consume more power than the other designs"***

   Well, apparently. But, the fact is, the puller won't be able to sustain torque voltage corresponding to 3.5V in running conditions for long (as it can be using a battery!), because with the vehicle running, the puller won't be able to generate greater torque on the pedal, so the voltage will eventually drop, and the motor operation time practically go down automatically.

2) ***"What if I want to stop it in an even lower voltage, like 3.2?"***

   5V can be reduced to a lower voltage using a voltage divider. Experimentally we'll have to find the value of biasing voltage which maximizes its output to 3.2V.

CHAPTER 6

Integrating the Torque Sensor into the System

6.1 Introduction

This chapter particularly describes all the aspects of integrating the Torque Sensor (TS) into the system, starting from managing power source, through mechanical fitting, to testing the whole system's performance with it in lab conditions.

6.2 Introduction to the Torque Sensor

A torque sensor is a device for measuring and recording the torque on a rotating system. A torque sensor takes input from a DC voltage source and outputs voltage corresponding to torque applied on specified crank or shaft. The voltage output is linear with the applied torque, within its operating region.

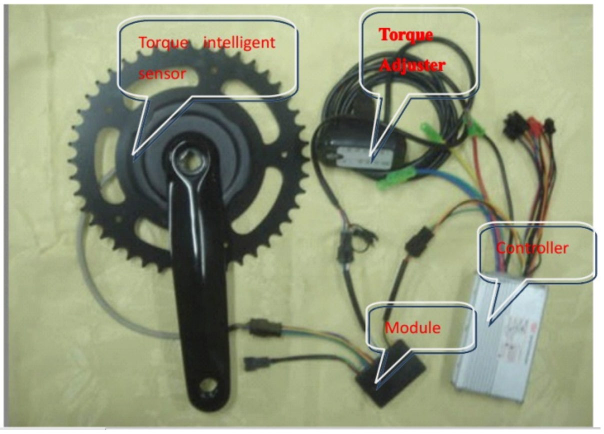

Fig. 6.1 Complete set-view of e-bike components including the Torque sensor [18]

To use with the system, the torque sensor setup was purchased from Suzhou Victory Sincerity Technology Company Ltd (http://www.jc-ebike.com). It is located in Suzhou, China. They undertake to develop, design and produce the components of e-bikes, mainly torque intelligent sensor system and relevant parts. The company has a group of experienced experts at designing and developing various e-bikes. They developed torque intelligent sensor system which conforms to the European standard-EN15194, Japanese JIS standard [18]. The torque sensor is their national patent product. They have integrated the sensor technology inside the pedal-system to use with bicycles. Only the sensor and module were used in the system.

6.3Features and Technical Data for the Torque Sensor:

6.3.1 Features: [18]

Fig. 6.2 The Torque Sensor

- Applicable to brush/brushless motor controllers
- Sensor/ Sensor-less motor-electrical system
- The hardware may be installed like a normal chain wheel crank.
- Instant responsebothonpedalpressureandwhen pedalling stopsor Pressureonthepedalsis reduced.
- Datacollectionpercrankrotation from 18to 96times.
- Aluminiumalloyis usedextensivelyfor the mainbodyparts
- Multi-poleintegrated magnetringwhichhasgreatlyimprovedtheprecisionofsignalsampling.

6.3.2Technical Parameter Data [18]

- Vcc = 5.15 V (+/- 0.15V)
- Output torque >15N-m
- Output, linear, zero-start, 0.5~4.5V
- Delay time < 50ms

6.4Mechanical Assembly:

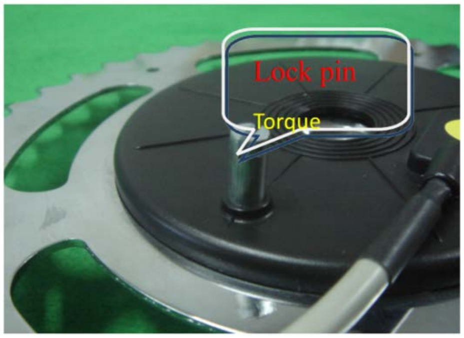

Fig. 6.3 The lock-pin at the back of the sensor [18]

The sensor was built in such a way that it could be fixed in any bicycle. However, for assembling it in a rickshaw made in Bangladesh, it needed a few mechanical modifications like reshaping the main pedal axis ends etc. A lock pin is used at the back of the sensor to stabilize the measuring circuitry while flexing the chain-wheel crack so that the torque can be measured.

6.5 Electrical Connections

The manufacturing company provides electrical connection diagram for the entire setup including the brushless-controller, torque adjustor etc. But in the system we will only be using the torque sensor and the corresponding signal-processing module (fig. 6.1). According to the diagram, there exist separate mechanisms for the sensor and module to get input voltages from the controller connections. But in the system, a different controller will be incorporated with the sensor. So, the independent operation connection diagram was extracted from the main diagram.

Fig. 6.4 The torque-sensor pedal assembled replacing the old pedal

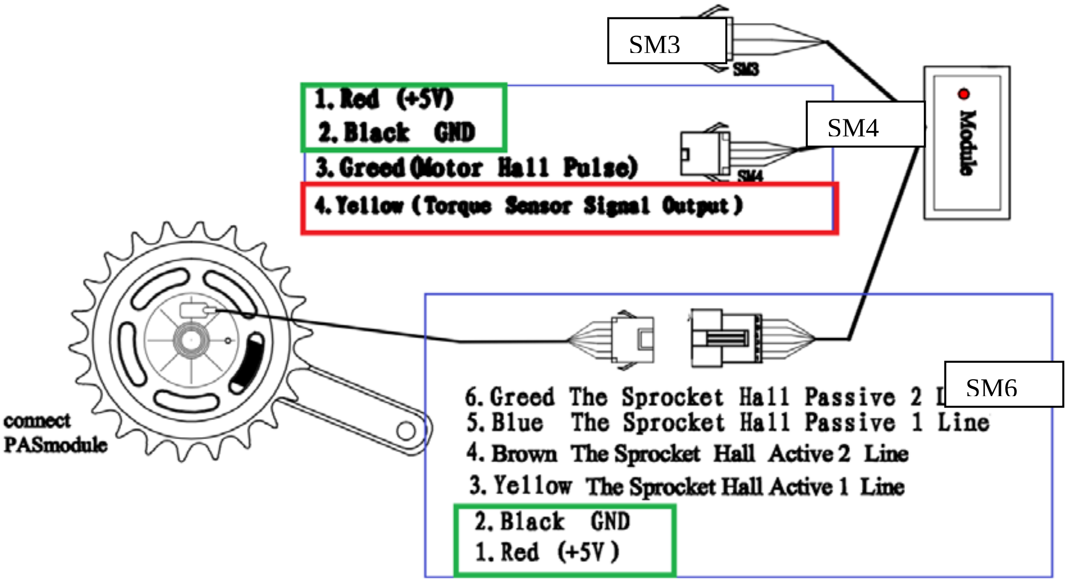

Fig. 6.5 Electrical Connection diagram for independent operation of the sensor and module

The figure above indicates that the input biasing terminals for the sensor are the Red and Black wires from SM6 (marked as +5V and GND). The input voltages are also marked in

SM4 for the module. The Yellow wire from SM4 is the processed output from the torque sensor which will be used for motor control. This wire gives the output voltage with respect to GND according to applied torque in the pedal-crank of the sensor. So, this is the output which is supposed to be fed to the external control circuit.

6.6 Managing the Power-Source

For implementation of the system, it was necessary that all power is sourced from the main Rickshaw battery which is four 12V batteries in series. The external circuit design from Chapter 5 and the torque sensor specification setup require that only a +5V source is necessary to power all these devices. So, an LM7805 voltage regulator was used to serve the purpose (See Appendix for more information on LM7805). The power management used in the system is evident from fig. 6.6.

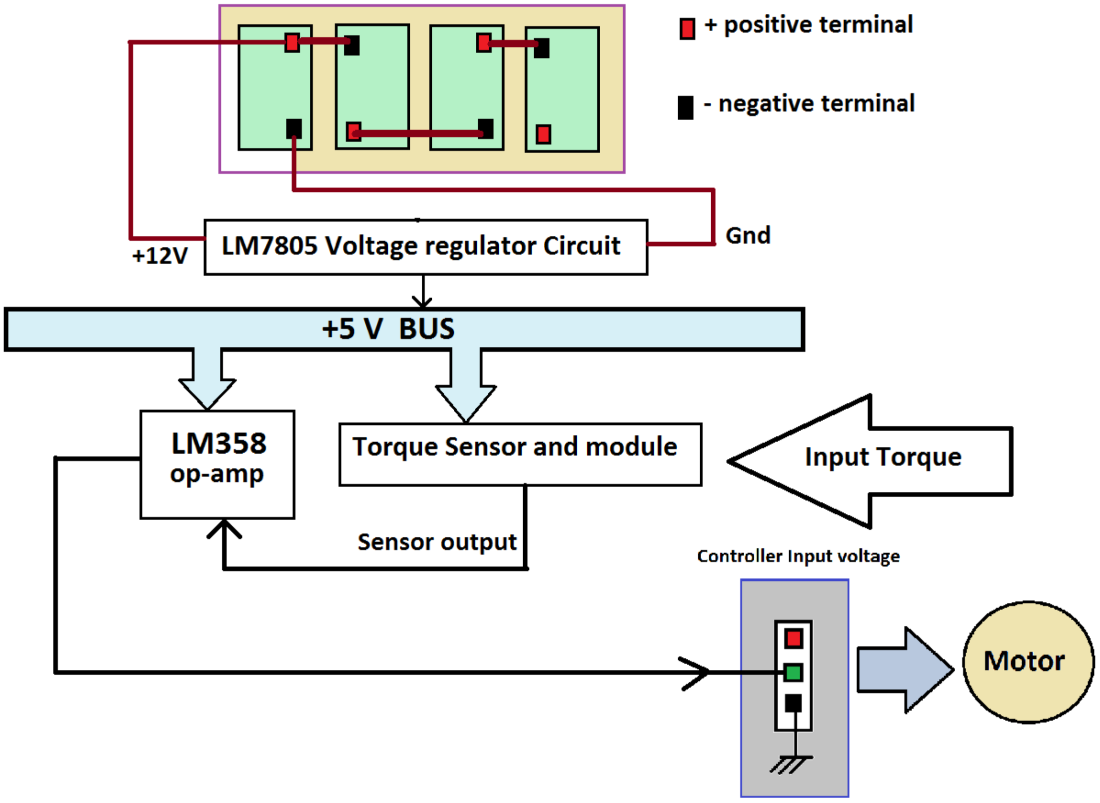

Fig. 6.6 A complete overview of the power management and signal flow

Fig. 6.7 shows the hardware implementation of the system in PCB.

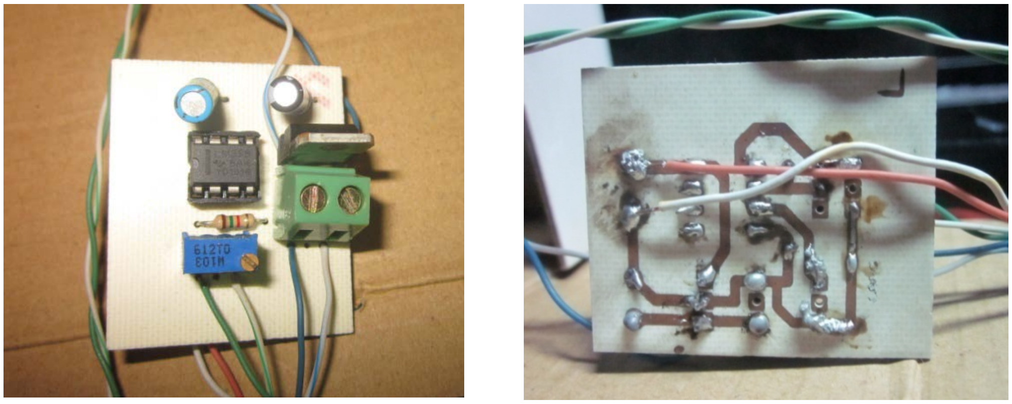

Fig. 6.7 Hardware implementation of the system in PCB.

6.7 Testing the Whole System in Lab Conditions:

The whole system was tested in the lab after implementation of the PCB board as the extensional control circuit. This time, the sensor was used in action and the system was run as it is supposed to ply on road. The wheels were connected and load was generated by generating friction on the wheels for testing the performance of it with the torque sensor. The friction and load-dynamics from the road was kept in mind and imitated as approximate possible. Fig. 6.9 shows the CU input voltage and wheel rpm characteristics for a preset gain of 1.5, which was set as an approximate comfortable ease of the machine.

During the first few seconds, the pedal was rotated with no external load, so the voltage was zero and the corresponding rpm in this region is due to the pedaling effort. A load-friction was then provided in the wheel and was increased with time. The motor started and pedaling seemed easier as the motor was assisting the pedaling effort. With a more increase in load, it was noticed that the maximum output voltage sustained at 3.5V as desired. Then the load was removed and the wheels were left to move freely. Then pedaling became very comfortable and even a nominal pedaling speed (just to keep the continuation) corresponded to 2.6 V and the motor also rotated at 2.6 volts' corresponding wheel speed. The rpm has a declining nature because of the gradual decrease in pedaling speed. The CU input voltage dropped to zero at the moment the pedaling stopped. Then the wheel rotated a few seconds with the inertia.

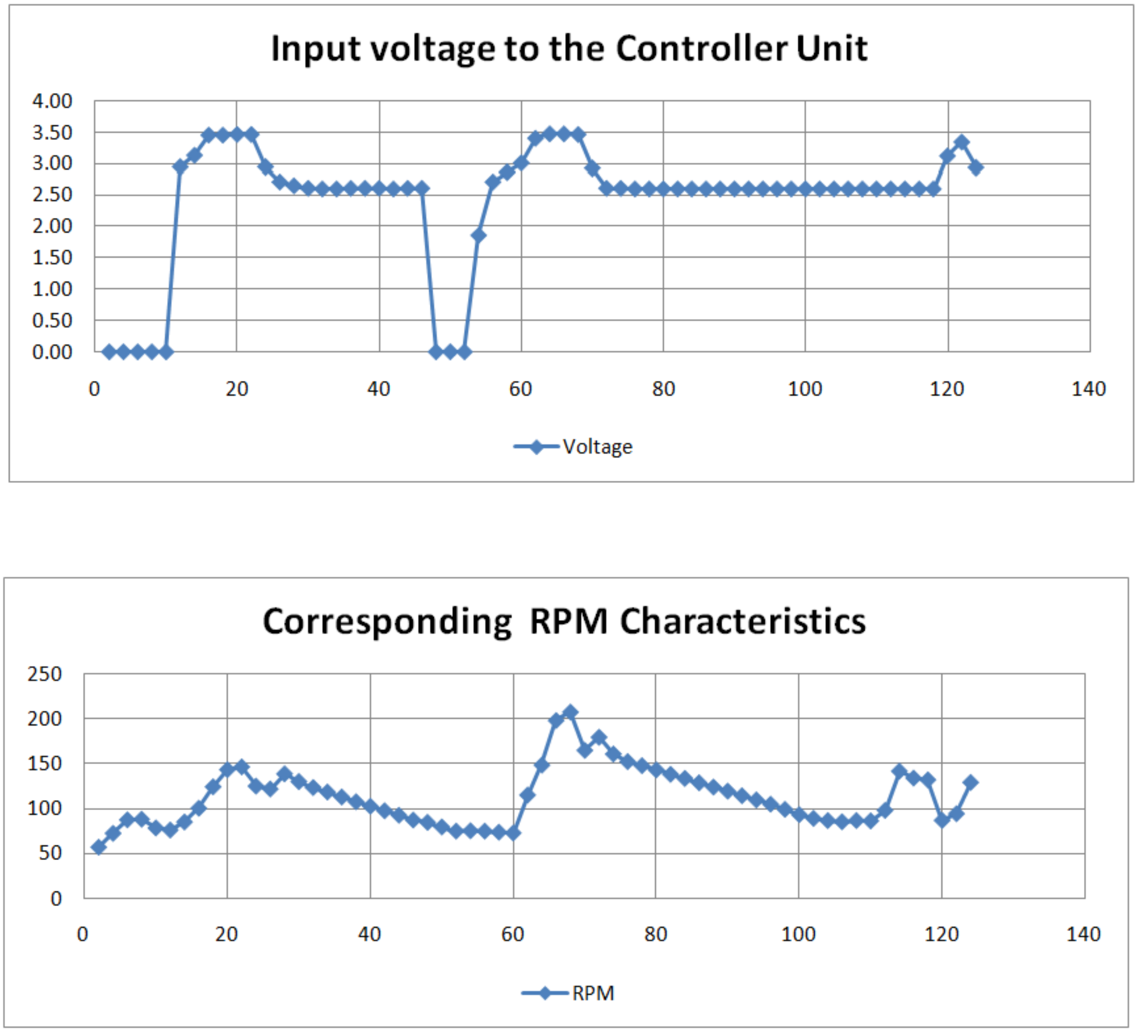

Fig 6.8 CU input voltage and corresponding rpm characteristics in lab conditions

The same loading process was repeated and found similar results as apparent from fig. 6.9.Due to the need of continuous data collection, a video camera was used to record all the data from adjacently placed multimeter and tachometer. Then it was replayed and paused with an approximate interval of a second to note the data.

6.8 Conclusion

The behaviour of the whole system in lab condition was satisfactory and no unexpected performance took place during a few hours of experimentation and testing. The system was ready for field test and practical observation.

CHAPTER 7

Accessories Installation

7.1 Introduction

Inadequate lighting on city streets results in a high sense of insecurity among cycle rickshaw passengers travelling after dark, as well as an increase in the frequency of rickshaw accidents. The consequent economic burden is multifold – medical bills, rickshaw repair cost, lost hours of income, inability to meet to daily sustenance resulting in dependence on money lenders etc. [19].

The problem is severe in the urban areas of Bangladesh where rickshaw pullers are frequently vulnerable to load-shedding and ‘light-less’ streets. So, the necessity of a headlight was apparent. Moreover, the battery power-system in the proposed improved model of rickshaw leaves a chance to use it for some other purposes like introducing headlights, indicator lights, and honks. Also, a charge indicator was necessary for the puller to be aware of the battery-charge condition throughout the working day.

This chapter will discuss the aspects of accessories installation and also highlight their power-consumption data making a sense of feasibility of these with the system.

7.2 Accessories Installation

7.2.1 The Charge Indicator, Headlight and Honk Setup-Module

A complete setup module including a 48V headlight, honk and battery-power indicator was used with the system (fig. 7.1). This setup is particularly used in battery run e-bikes and manufactured in China. Due to unavailability of technical data and operation manual, the connection technique of this was also reverse engineered. The results are shown in fig. 7.2.

There were 4 LEDs on top displaying the batteries’ charge state and a multiple LED low-power headlight in front. The honk was integrated inside the module and could be operated using an external switch where for the headlight, a key-switch was provided (fig. 7.1).

The charge indicator did not have a switch. It showed the state-of-charge of the batteries from the moment it was connected across the 48V batteries. So an external switch was added in order to limit its overuse or undesired use.

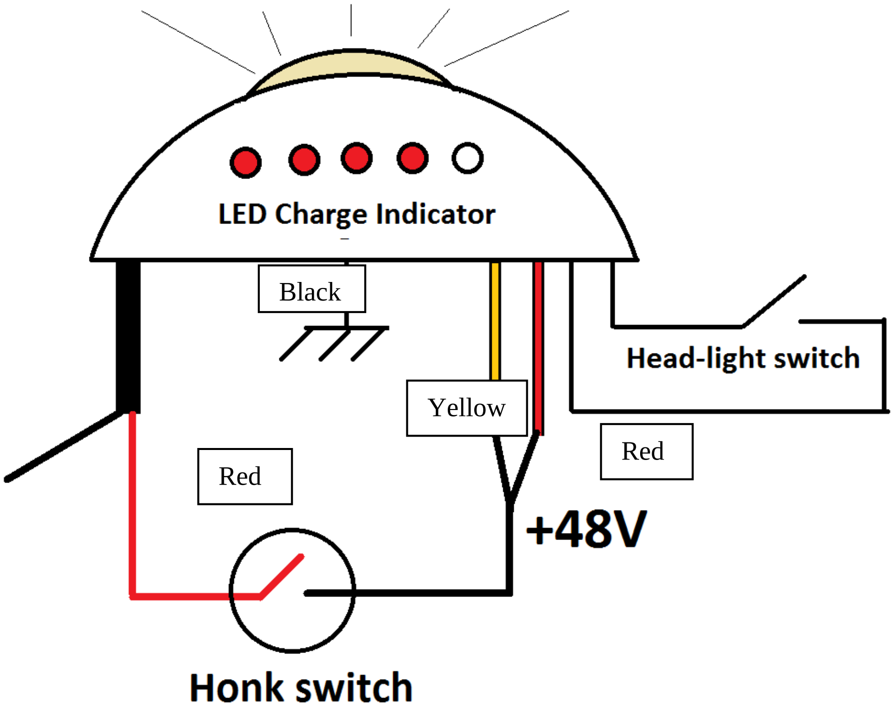

Fig. 7.1 The Accessories setup-module connection diagram

7.2.2 The Indicator lights

Indicator lights are important mainly because the driver needs to be pedaling the vehicle to run and it is difficult to signal the other drivers in the back to indicate its turning direction. Usually in the traditional rickshaws, they use their hands waving to indicate their directions to the other drivers. In the system, motorbike indicator lights are used to serve the purpose. These are typically 12V lights used in most motorbikes in the market. The use of four 12V batteries in the rickshaw made it easy to use them for different other purposes like this one. Fig. 7.3 shows the lights installed in the system, and fig. 7.4 shows the power management of all the accessories from the main power source.

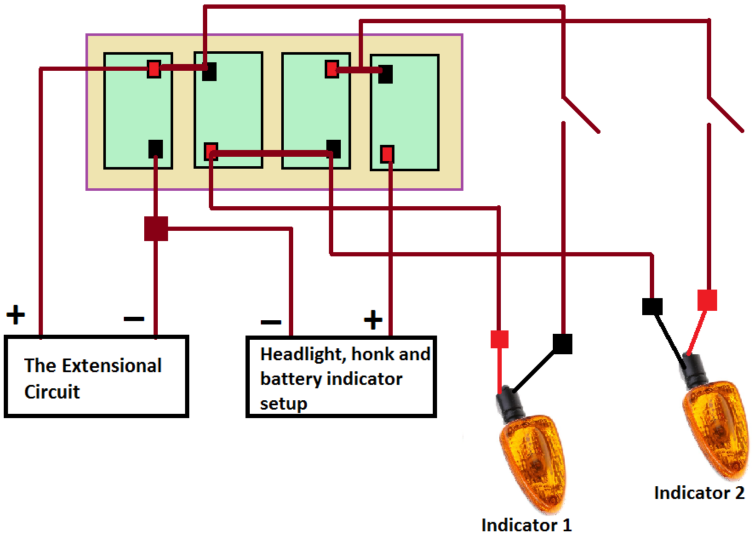

Fig 7.2 Power management of the accessories

7.3 Power Consumption by the Accessories

The power consumption by each accessory was calculated by measuring its terminal voltage and the current drawn from battery when each item is turned 'ON'. Table 7.1 illustrates the power calculation data.

The battery-level indicator is always on when the module is on. So, at first, only the current drawn for the battery-indicator is measured. Then, all other items' current readings were taken 'including' the battery-indicator. Then the individual currents were recovered subtracting it from those readings.

Item	Voltage (Volts)	Current (Amp.)	Power (watts)
Battery-Level Indicator (BLI)	51.2	0.01	0.512
BIL + Headlight Only Headlight	51.2 51.2	0.04 .04-.01= 0.03	2.048 1.536
BLI + honk Only honk	51.2 51.2	0.07 0.07-0.01= 0.06	3.584 3.072
BLI + honk + headlight	51.2	.10	5.12
Indicator lights (2)	12.8	0.6	7.68

Table 7.1 Power consumption data for the accessories

Table 7.1 shows that a very negligible power is drawn from the components with respect to the 500W motor to be used with the system. Moreover, the accessories will not be used continuously but when needed during the ride. For example, the headlight only operates after dusk; the indicators will operate only during left or right turns; and the honk when needed. So, the total energy consumption will be even more negligible. However, lower-power LED indicator lights can be integrated with the system to reduce energy consumption. The one included in the model was subject to availability of the components in local market.

7.4 Conclusion

This chapter highlighted the feasibility of introducing modern accessories into this model of rickshaw which is very likely to decrease accident possibilities and help improve the life of the rickshaw-puller community. And, also shows that they do not cause significant power consumption.

CHAPTER 8

Field-Tests and Analysis

8.1 Introduction

After completing the prototype and testing it in the lab-condition, it was brought under a field test to analyze its performance under practical road-conditions. The whole rickshaw was run in the ICDDR,B and Sattala area at Mohakhali, Dhaka for approximately 4 hours for test. A few data were also taken specially for analyzing its performance and power-efficiency. In this chapter, an overview of the field-test result will presented; the processed data will be interpreted in the figures and the system's efficiency over the throttle-controlled model of electric rickshaw will be presented numerically.

8.2 Objectives of the Field-Test

The major objectives of the field-test were:

- To see how the whole system behaves on road (i.e. is it really comfortable for both the rider and passenger?)
- To see if the motor control system is working properly and safely (i.e. if any hazardous situation takes place, like losing the control over the motor etc.)
- To analyze the dynamics of human pedaling for a rickshaw
- To picture the energy-consumption trend in the current design
- To picture the energy-consumption trend in the previous design (using throttle)
- A comparative analysis of energy consumption for both the models.
- Calculating the efficiency of the design with respect to the previous model, in-terms-of the energy consumed during a time period.
- How quickly the battery discharges

8.3 Qualitative Analysis

During the four hours of test, no hazardous condition took place like losing the control over motor and stopping it on emergency basis etc. From the passengers' point of view, it was more like riding the old rickshaws with a little high speed. Though the motor thrusts were felt at some points, it was not bothering the passengers much.

From the puller's interview it was evident that he felt easier to ride this rickshaw compared to the traditional ones. The puller also had the experience of driving the Beevatech model of throttle controlled electric rickshaw, but his opinion about this model was quite positive though it makes them use their muscular-energy to some extent. According to them the throttle controlled rickshaw is hard to pedal as it is nearly impossible to control the motor from throttle and pedal with feet at the same time. The lack of power-synchronization makes this design a better hybrid model over the previous. The rickshaw puller involved in the test also included that: *"It is not that hard to pull this rickshaw, however the Beevatech (throttle controlled one) rickshaw is easier as it is like riding a motorcycle and the motor is used throughout; consequently the battery discharged in 5-6 hours. But if this rickshaw can save the battery and let us run longer hours, with this level of easiness, we can run even upto 10-12 hours."*

8.4 Quantitative Analysis

8.4.1 Data taken for analysis

The following data were taken for the above mentioned analyses.

- The controller input voltage pattern analysis in both the models for comparison
- The pattern of current drawn from battery in both the models for comparison
- What is the percentage of battery-charge after 4 hours of run

From the current-drawing pattern of both the models, the following data were achieved.

- The power consumption pattern by the motor (the other power-consumptions are negligible)
- The total-energy consumption by the motor in a particular time-interval
- A comparison between the two models.

8.4.2 Data Acquisition Technique

Due to the unavailability of modern data acquisition techniques, a video camera is used to record the data from multi-meters and then replayed and paused in regular intervals of approximately 1 second and noted. Then the recorded data were plotted to represent in figures for better understanding. A snapshot from the video is shown in fig. 8.1.

Fig. 8.1 Snapshot from a data acquisition

8.4.3 The Riding Pattern Analysis

It has been mentioned earlier that the motor speed is controlled by a voltage signal which feeds to the CU-input terminals and comes from the throttle in the previous design. In the proposed model the signal comes from the torque sensor via the extensional control unit limiting the maximum output to 3.5 V.

The riding pattern means, using the torque sensor, what is the characteristic of the voltage signal that is going to the CU. This pattern is approximately the direct representation of the torque sensor output which corresponds to the pedaling dynamics in a particular interval.

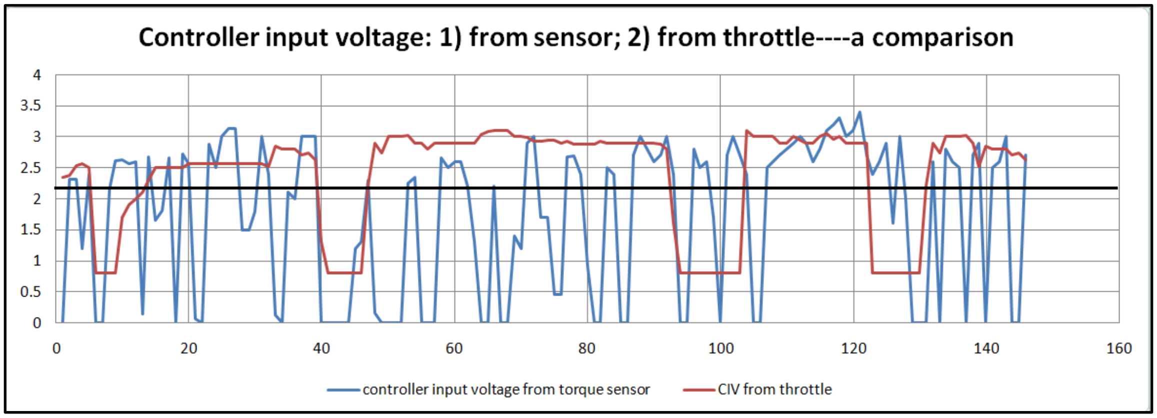

Fig. 8.2 A comparative illustration of the Controller Input Voltage characteristics in both the models

Fig. 8.2 illustrates the controller input voltage characteristics in both the models. The red curve in the figure shows the typical throttle control characteristics of a rickshaw puller on road. And the blue curve corresponds to the torque sensor output going through the external controller amplifier and output limiting mechanism. The black line is drawn corresponding to 2.2V, the starting voltage of the motor. So, part of the curve above the black line is the motor drive region. It is apparent from the figure that the throttle controller model involved more use of the motor, however it will be numerically proved that the new design ensures less use of the motor and involves a combination of man-machine power to drive the vehicle.

8.4.4 The Current-Draw data

This was the most significant data obtained from the field test, because current drawn from battery directly corresponds to the power-consumed. The previous data does picture the use of motor but it does not illustrate how much power is consumed. For example: at the beginning of the run, the load is maximum, and then evens a lower CU input voltage like 2.5 may correspond to high armature current in the motor resulting higher power-consumption than a 3.5V CU input at running condition on free road. So, the data was of significant information. This data was also used to figure out the power-curve and hence the total energy calculation in a particular interval.

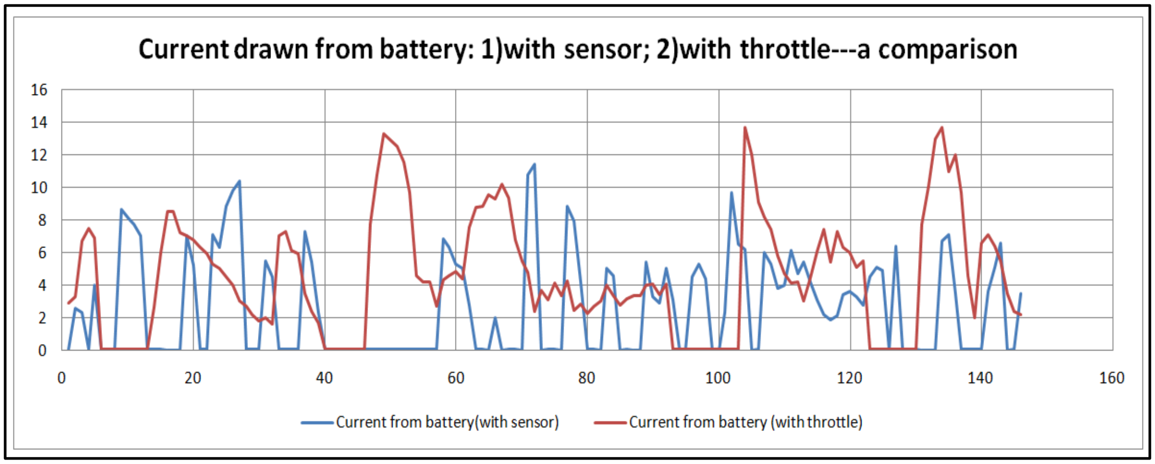

Fig. 8.3 Current drawn from battery in test-run; using throttle (red); and using sensor (blue)

8.4.5 The Power Curve

The power curve can be derived from the current drawing nature of both the systems. Since the power in nothing but the terminal voltage multiplied by the current drawn, the power curve can be derived from the current curve. Each value is multiplied by the terminal voltage 51.2 Volts and plotted in figure 8.4.

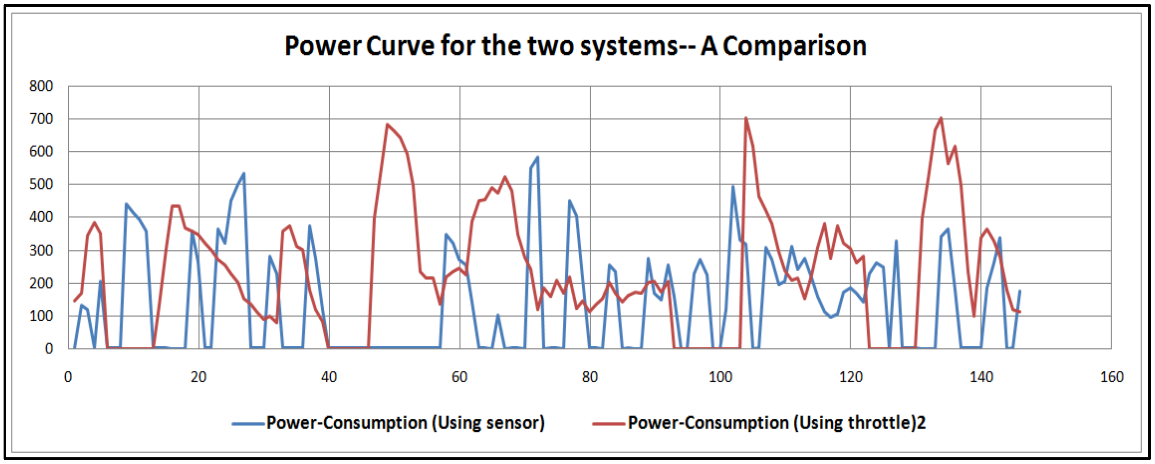

Fig. 8.4 The power-consumption curve for the two systems in a test-period; using sensor (blue), using throttle (red)

8.4.6 Calculation of the Total energy

Area under the power curve represents the total electrical energy consumption in the sample testing period. The area is calculated numerically using the trapezoidal rule. However, the lower energy consumption is apparent from fig 8.5 where the area for the implemented system is shown in front and the existing at back.

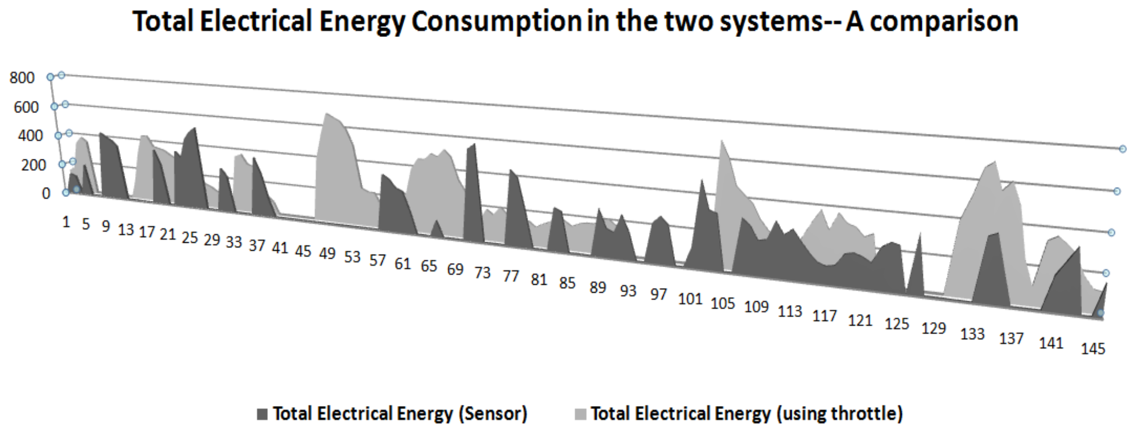

Fig. 8.5 A graphical overview of total energy consumption during the test period

In the test period, the total energy consumption using trapezoidal rule are as follows:

Total energy consumption (sensor): 19472.62 Joules appx.

Total energy consumption (throttle): 33665.02 Joules appx.

So, this system consumes 57.84 % energy of the throttle controlled design yet providing sufficient assistance to the user. Hence, it saves **42.16%** energy.

8.5 Conclusion

This chapter numerically proves the efficiency of the implemented system using practical field test data. It was also evident from the fact that after four long hours of field test more than 80% charge was still left in the battery (as the battery-level indicator showed). The system also lengthen the battery life as a consequence of using the sensor—that means by not letting close to rated current flow for a longer time, which is frequent in the throttle controlled system.

CHAPTER 9

Conclusions

9.1 Summary

The electrical and electronic development of the project *Torque Sensor Based Electrically Assisted Hybrid Rickshaw* was a success after twelve months of research. They key objective of this project was to design and develop all technical aspects for the system and end up with a final prototype. The entire control system and other supporting modernizations were designed and developed over the platform of an existing model of electric rickshaw. The prototype also came across a field test and proved its significant efficiency over all other commercial models. This efficiency paves the way to think about its future involvement with renewable energy. The proposed recharging infrastructure using Solar Battery Charging Station (SBCS) and other future works will be described in the following chapters.

9.2 Proposed Recharging Infrastructure

The goals that we established for the design of the recharging infrastructure are:

- There should be a battery-swapping process rather than using solar-panels attached over the vehicle; because that is firstly inefficient, secondly vulnerable to unexpected social problems like getting theft etc.
- The battery swapping process should be as efficient and effective as possible and should be a role model for the next generation sustainable refueling infrastructure.
- Maximize the amount of energy to be produced by renewable energy sources.

To establish the above mentioned goals, it was decided to go for a "*Central Solar Battery Charging Station*" concept. The batteries charged at a central location ensure better maintenance by trained people thus longevity of the battery packs. Moreover, it is not wise to overload the national grid for this purpose, as the power grid in Bangladesh is weak in the urban areas other than the capital.

The idea is, various types of batteries including the 12V Solar Home System (SHS) may be charged using sophisticated technologies and advanced protection techniques in the multipurpose central SBCS. A diesel generator may be used as a backup for cases like days with insufficient sunlight.

The rickshaw pullers will bring their rickshaw to the central SBCS and swap their discharged batteries with a recharged one from the station just like petrol refueling as shown in fig. 9.1

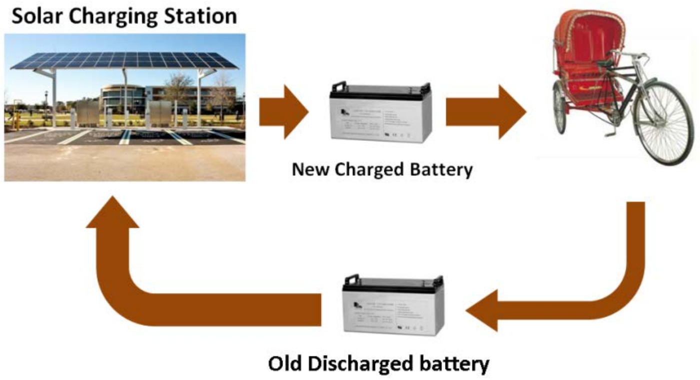

Fig. 9.1 Concept of the Central SBCS

9.3 Future Works

So, far the prototype implementation of the project was completed. The *Control and Applications Research Group* has a vision towards taking this as a pilot project and implementing the technology in few more rickshaws for taking real feedback and hence continuous development. Moreover, a basic goal of the project to transform the existing resources of traditional rickshaws to this new model is still to be done. These will be done by professional mechanics in future to develop a cost-effective and stably transformed architecture in order to ensure the use of existing resources.

Using this technology, there are also scopes of future research to develop more power-assisted models of different other vehicles like rickshaw-vans, bicycles, and even power-assisted wheelchairs for paraplegic patients.

9.4 Publications

1. R. M. Huq, Md. A. Hoque, P. Chakraborty, N. T. Shuvo, A. K. M. Azad, “Development of Torque Sensor Based Electrically Assisted Hybrid Rickshaw,” Submitted to 7th International Conference on Electrical and Computer, Engineering, Dhaka, Bangladesh, 20-22 December 2012.

2. T. Faraz, A. K. M. Azad, “Solar Battery Charging Station and Torque Sensor Based Electrically Assisted Tricycle,” accepted at Graduate Students Technical Conference, (GSTC), Ellensburg, WA, USA.

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APPENDIX

KA78XX/KA78XXA

3-Terminal 1A Positive Voltage Regulator

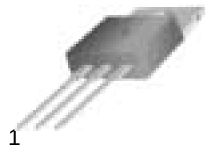
Features

- Output Current up to 1A
- Output Voltages of 5, 6, 8, 9, 10, 12, 15, 18, 24V
- Thermal Overload Protection
- Short Circuit Protection
- Output Transistor Safe Operating Area Protection

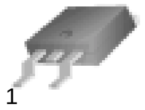
Description

The KA78XX/KA78XXA series of three-terminal positive regulator are available in the TO-220/D-PAK package and with several fixed output voltages, making them useful in a wide range of applications. Each type employs internal current limiting, thermal shut down and safe operating area protection, making it essentially indestructible. If adequate heat sinking is provided, they can deliver over 1A output current. Although designed primarily as fixed voltage regulators, these devices can be used with external components to obtain adjustable voltages and currents.

TO-220

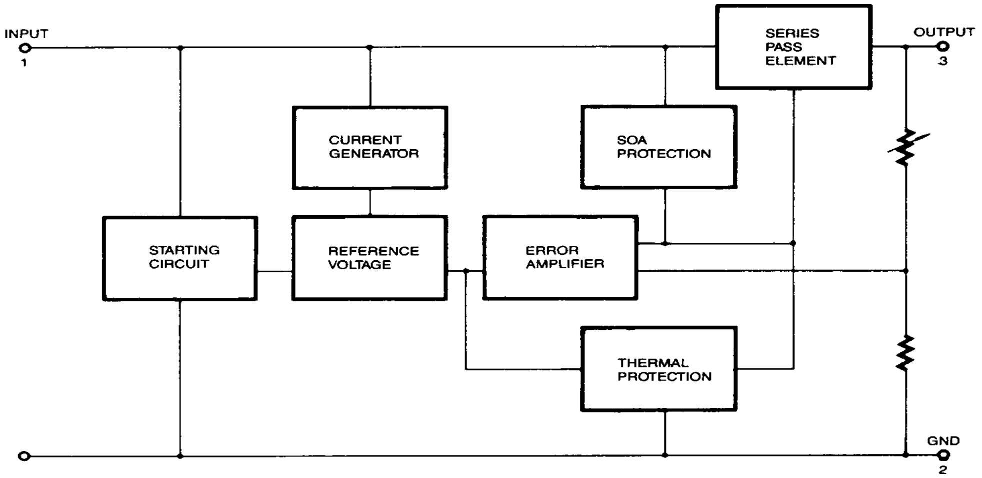


D-PAK



1. Input 2. GND 3. Output

Internal Block Digram



Rev. 1.0.0

Absolute Maximum Ratings

Parameter	Symbol	Value	Unit
Input Voltage (for V_O = 5V to 18V) (for V_O = 24V)	V_I V_I	35 40	V V
Thermal Resistance Junction-Cases (TO-220)	$R_{\theta JC}$	5	°C/W
Thermal Resistance Junction-Air (TO-220)	$R_{\theta JA}$	65	°C/W
Operating Temperature Range (KA78XX/A/R)	T_{OPR}	0 ~ +125	°C
Storage Temperature Range	T_{STG}	-65 ~ +150	°C

Electrical Characteristics (KA7805/KA7805R)

(Refer to test circuit ,0°C < T_J < 125°C, I_O = 500mA, V_I =10V, C_I= 0.33μF, C_O=0.1μF, unless otherwise specified)

Parameter	Symbol	Conditions		KA7805			Unit
				Min.	Typ.	Max.	
Output Voltage	V_O	T_J =+25 °C		4.8	5.0	5.2	V
		5.0mA ≤ Io ≤ 1.0A, P_O ≤ 15W V_I = 7V to 20V		4.75	5.0	5.25	
Line Regulation (Note1)	Regline	T_J=+25 °C	V_O = 7V to 25V	-	4.0	100	mV
			V_I = 8V to 12V	-	1.6	50	
Load Regulation (Note1)	Regload	T_J=+25 °C	I_O = 5.0mA to1.5A	-	9	100	mV
			I_O =250mA to 750mA	-	4	50	
Quiescent Current	I_Q	T_J =+25 °C		-	5.0	8.0	mA
Quiescent Current Change	ΔI_Q	I_O = 5mA to 1.0A		-	0.03	0.5	mA
		V_I= 7V to 25V		-	0.3	1.3	
Output Voltage Drift	$\Delta V_O/\Delta T$	I_O= 5mA		-	-0.8	-	mV/ °C
Output Noise Voltage	V_N	f = 10Hz to 100KHz, T_A=+25 °C		-	42	-	μV/V_O
Ripple Rejection	RR	f = 120Hz V_O = 8V to 18V		62	73	-	dB
Dropout Voltage	V_{Drop}	I_O = 1A, T_J =+25 °C		-	2	-	V
Output Resistance	r_O	f = 1KHz		-	15	-	mΩ
Short Circuit Current	I_{SC}	V_I = 35V, T_A =+25 °C		-	230	-	mA
Peak Current	I_{PK}	T_J =+25 °C		-	2.2	-	A

Note:

1. Load and line regulation are specified at constant junction temperature. Changes in V_O due to heating effects must be taken into account separately. Pulse testing with low duty is used.

Electrical Characteristics (KA7805A)

(Refer to the test circuits. $0^{o}C < T_J < +125\,^{o}C$, I_O =1A, V_I = 10V, C_I=0.33µF, C_O=0.1µF, unless otherwise specified)

Parameter	Symbol	Conditions		Min.	Typ.	Max.	Unit
Output Voltage	V_O	T_J =+25 °C		4.9	5	5.1	V
		I_O = 5mA to 1A, $P_O \leq$ 15W V_I = 7.5V to 20V		4.8	5	5.2	
Line Regulation (Note1)	Regline	V_I = 7.5V to 25V I_O = 500mA		-	5	50	mV
		V_I = 8V to 12V		-	3	50	
		T_J =+25 °C	V_I= 7.3V to 20V	-	5	50	
			V_I= 8V to 12V	-	1.5	25	
Load Regulation (Note1)	Regload	T_J =+25 °C I_O = 5mA to 1.5A		-	9	100	mV
		I_O = 5mA to 1A		-	9	100	
		I_O = 250mA to 750mA		-	4	50	
Quiescent Current	I_Q	T_J =+25 °C		-	5.0	6.0	mA
Quiescent Current Change	ΔI_Q	I_O = 5mA to 1A		-	-	0.5	mA
		V_I = 8 V to 25V, I_O = 500mA		-	-	0.8	
		V_I = 7.5V to 20V, T_J =+25 °C		-	-	0.8	
Output Voltage Drift	$\Delta V/\Delta T$	Io = 5mA		-	-0.8	-	mV/ °C
Output Noise Voltage	V_N	f = 10Hz to 100KHz T_A =+25 °C		-	10	-	µV/Vo
Ripple Rejection	RR	f = 120Hz, I_O = 500mA V_I = 8V to 18V		-	68	-	dB
Dropout Voltage	V_{Drop}	I_O = 1A, T_J =+25 °C		-	2	-	V
Output Resistance	r_O	f = 1KHz		-	17	-	mΩ
Short Circuit Current	I_{SC}	V_I= 35V, T_A =+25 °C		-	250	-	mA
Peak Current	I_{PK}	T_J= +25 °C		-	2.2	-	A

Note:

1. Load and line regulation are specified at constant junction temperature. Change in V_O due to heating effects must be taken into account separately. Pulse testing with low duty is used.

Typical Perfomance Characteristics

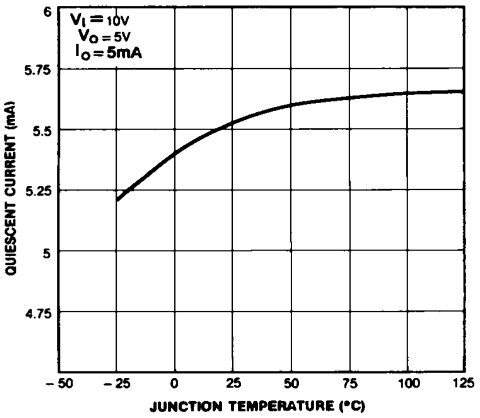


Figure 1. Quiescent Current

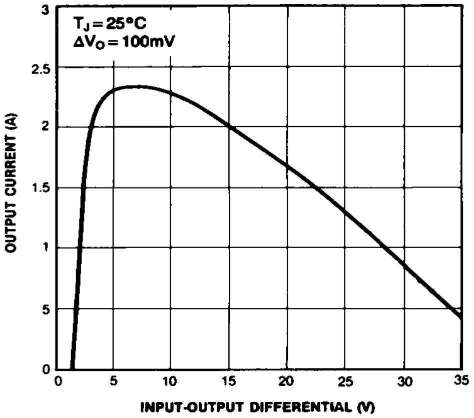


Figure 2. Peak Output Current

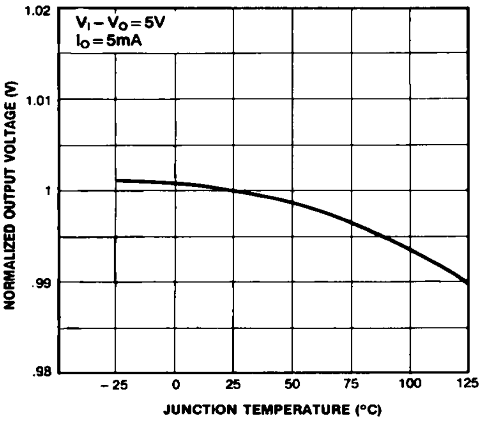


Figure 3. Output Voltage

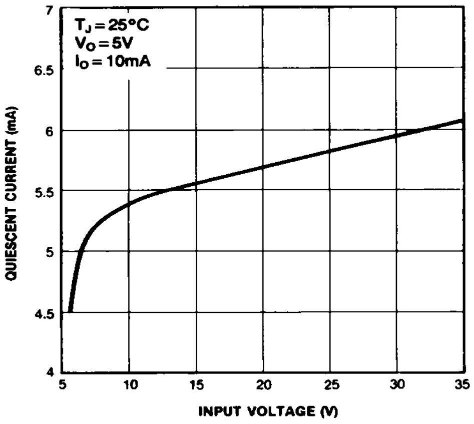


Figure 4. Quiescent Current

Typical Applications

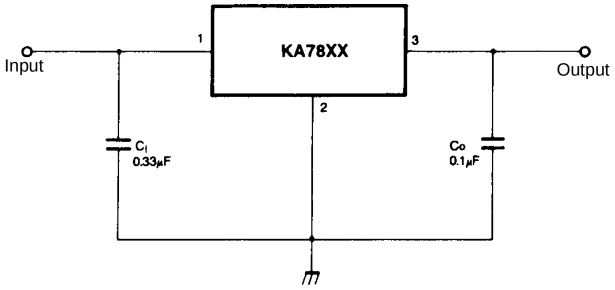


Figure 5. DC Parameters

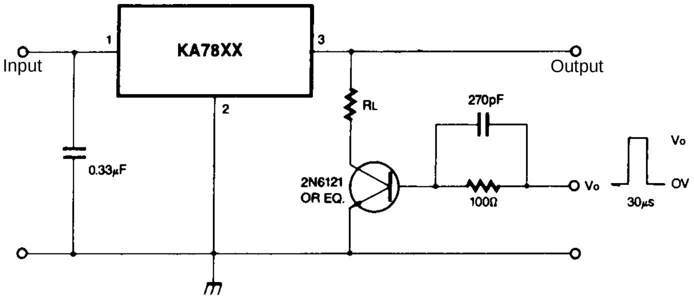


Figure 6. Load Regulation

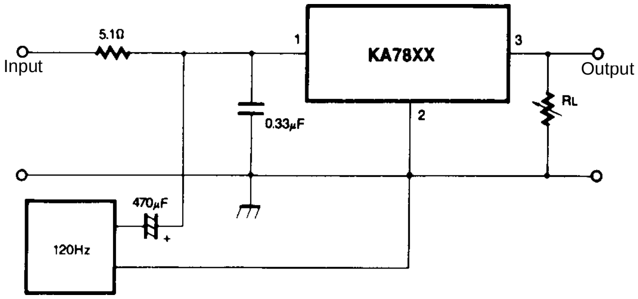


Figure 7. Ripple Rejection

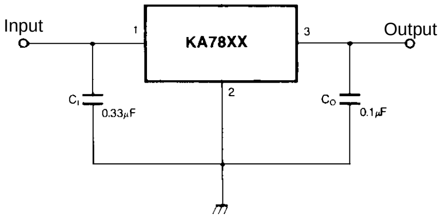
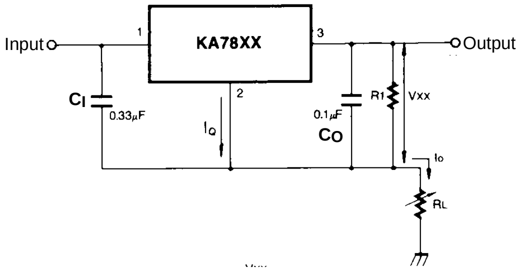


Figure 8. Fixed Output Regulator



$$I_O = \frac{V_{XX}}{R_1} + I_Q$$

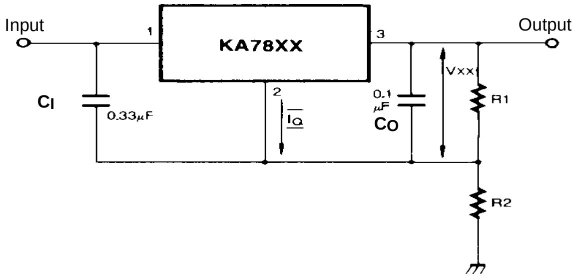
Figure 9. Constant Current Regulator

Notes:

(1) To specify an output voltage. substitute voltage value for "XX." A common ground is required between the input and the Output voltage. The input voltage must remain typically 2.0V above the output voltage even during the low point on the input ripple voltage.

(2) C_I is required if regulator is located an appreciable distance from power Supply filter.

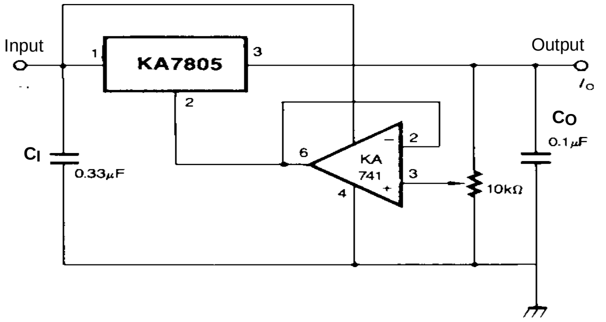
(3) C_O improves stability and transient response.



$I_{RI} \geq 5I_Q$

$V_O = V_{XX}(1+R_2/R_1)+I_QR_2$

Figure 10. Circuit for Increasing Output Voltage



$I_{RI} \geq 5\ I_Q$

$V_O = V_{XX}(1+R_2/R_1)+I_QR_2$

Figure 11. Adjustable Output Regulator (7 to 30V)

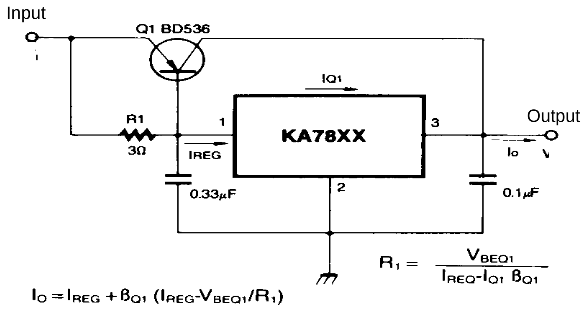


Figure 12. High Current Voltage Regulator

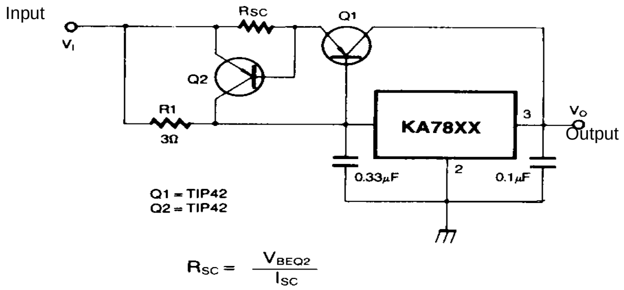


Figure 13. High Output Current with Short Circuit Protection

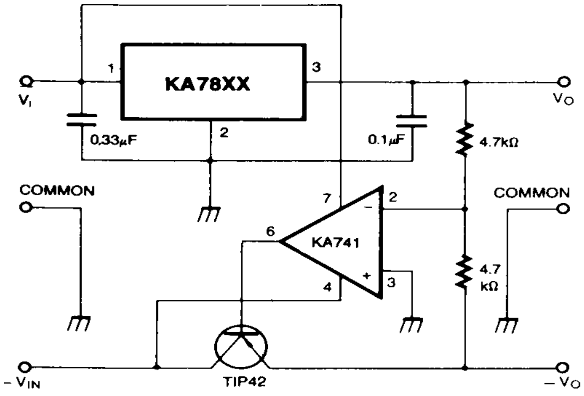


Figure 14. Tracking Voltage Regulator

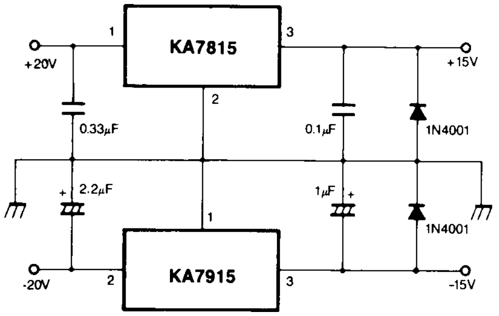


Figure 15. Split Power Supply (±15V-1A)

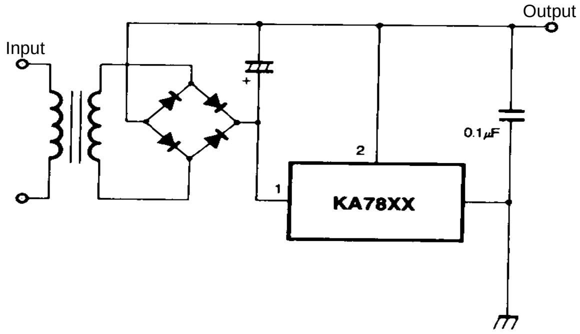


Figure 16. Negative Output Voltage Circuit

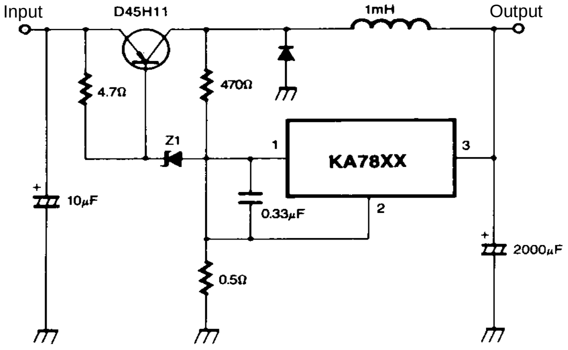


Figure 17. Switching Regulator

LM2904,LM358/LM358A,LM258/ LM258A

Dual Operational Amplifier

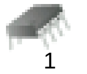
Features

- Internally Frequency Compensated for Unity Gain
- Large DC Voltage Gain: 100dB
- Wide Power Supply Range:
  LM258/LM258A, LM358/LM358A: 3V~32V (or ±1.5V ~ 16V)
  LM2904 : 3V~26V (or ±1.5V ~ 13V)
- Input Common Mode Voltage Range Includes Ground
- Large Output Voltage Swing: 0V DC to Vcc -1.5V DC
- Power Drain Suitable for Battery Operation.

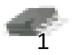
Description

The LM2904,LM358/LM358A, LM258/LM258A consist of two independent, high gain, internally frequency compensated operational amplifiers which were designed specifically to operate from a single power supply over a wide range of voltage. Operation from split power supplies is also possible and the low power supply current drain is independent of the magnitude of the power supply voltage. Application areas include transducer amplifier, DC gain blocks and all the conventional OP-AMP circuits which now can be easily implemented in single power supply systems.

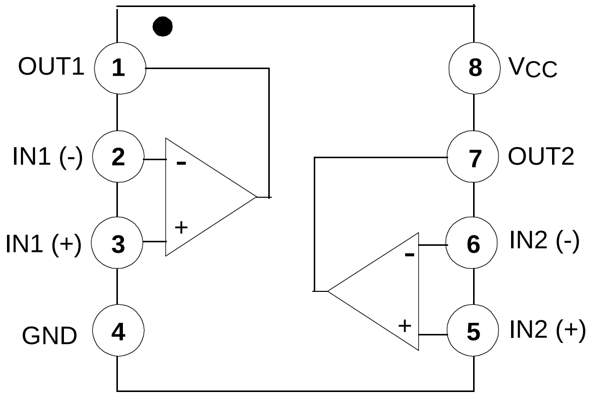
8-DIP



8-SOP



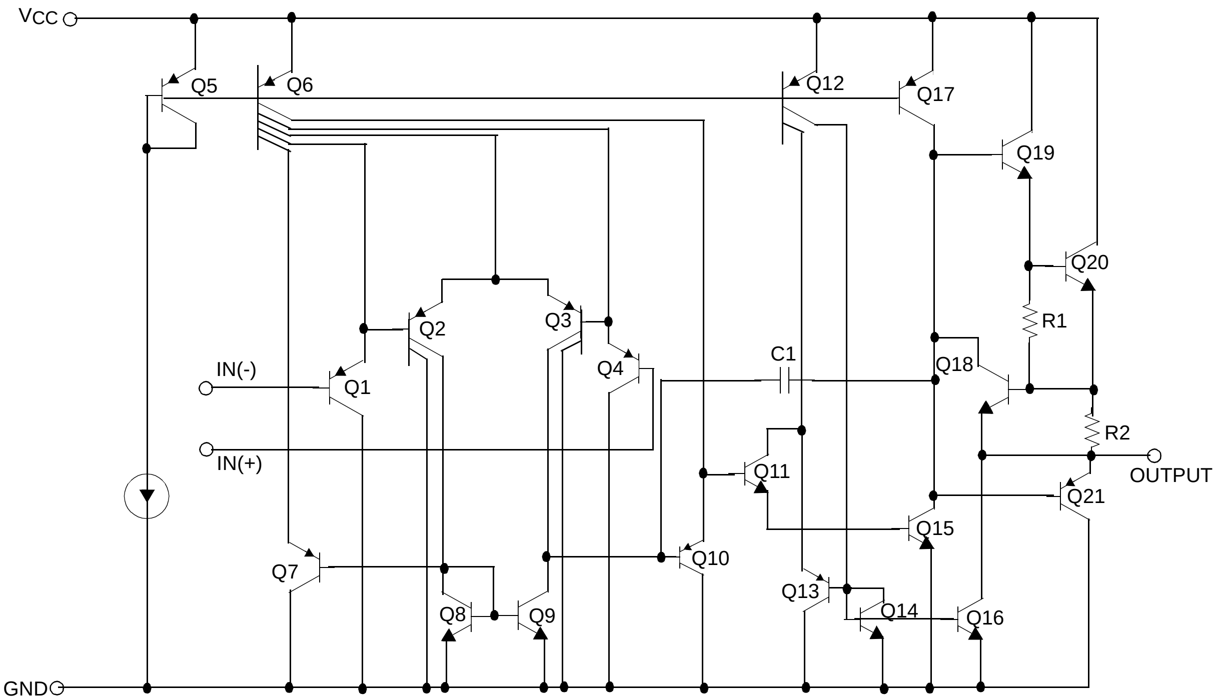
Internal Block Diagram



Rev. 1.0.2

Schematic Diagram

(One section only)



Absolute Maximum Ratings

Parameter	Symbol	LM258/LM258A	LM358/LM358A	LM2904	Unit
Supply Voltage	V_{CC}	±16 or 32	±16 or 32	±13 or 26	V
Differential Input Voltage	$V_{I(DIFF)}$	32	32	26	V
Input Voltage	V_I	-0.3 to +32	-0.3 to +32	-0.3 to +26	V
Output Short Circuit to GND V_{CC}≤15V, T_A = 25°C(One Amp)	-	Continuous	Continuous	Continuous	-
Operating Temperature Range	T_{OPR}	-25 ~ +85	0 ~ +70	-40 ~ +85	°C
Storage Temperature Range	T_{STG}	-65 ~ +150	-65 ~ +150	-65 ~ +150	°C

Electrical Characteristics

(Vcc = 5.0V, V_{EE} = GND, T_A = 25°C, unless otherwise specified)

Parameter	Symbol	Conditions	LM258			LM358			LM2904			Unit
			Min.	Typ.	Max.	Min.	Typ.	Max.	Min.	Typ.	Max.	
Input Offset Voltage	V_{IO}	V_{CM} = 0V to V_{CC} -1.5V $V_{O(P)}$ = 1.4V, R_S = 0Ω	-	2.9	5.0	-	2.9	7.0	-	2.9	7.0	mV
Input Offset Current	I_{IO}	-	-	3	30	-	5	50	-	5	50	nA
Input Bias Current	I_{BIAS}	-	-	45	150	-	45	250	-	45	250	nA
Input Voltage Range	$V_{I(R)}$	V_{CC} = 30V (LM2904, V_{CC}=26V)	0	-	Vcc -1.5	0	-	Vcc -1.5	0	-	Vcc -1.5	V
Supply Current	I_{CC}	R_L = ∞, V_{CC} = 30V (LM2904, V_{CC}=26V)	-	0.8	2.0	-	0.8	2.0	-	0.8	2.0	mA
		R_L = ∞, V_{CC} = 5V	-	0.5	1.2	-	0.5	1.2	-	0.5	1.2	mA
Large Signal Voltage Gain	G_V	V_{CC} = 15V, R_L= 2kΩ $V_{O(P)}$ = 1V to 11V	50	100	-	25	100	-	25	100	-	V/mV
Output Voltage Swing	$V_{O(H)}$	V_{CC}=30V (V_{CC} =26V for LM2904), R_L = 2kΩ	26	-	-	26	-	-	22	-	-	V
		R_L= 10kΩ	27	28	-	27	28	-	23	24	-	V
	$V_{O(L)}$	V_{CC} = 5V, R_L= 10kΩ	-	5	20	-	5	20	-	5	20	mV
Common-Mode Rejection Ratio	CMRR	-	70	85	-	65	80	-	50	80	-	dB
Power Supply Rejection Ratio	PSRR	-	65	100	-	65	100	-	50	100	-	dB
Channel Separation	CS	f = 1kHz to 20kHz (Note1)	-	120	-	-	120	-	-	120	-	dB
Short Circuit to GND	I_{SC}	-	-	40	60	-	40	60	-	40	60	mA
Output Current	I_{SOURCE}	$V_{I(+)}$ = 1V, $V_{I(-)}$ = 0V V_{CC} = 15V, $V_{O(P)}$ = 2V	20	30	-	20	30	-	20	30	-	mA
	I_{SINK}	$V_{I(+)}$ = 0V, $V_{I(-)}$ = 1V, V_{CC} = 15V, $V_{O(P)}$ = 2V	10	15	-	10	15	-	10	15	-	mA
		$V_{I(+)}$ = 0V,$V_{I(-)}$ =1V , V_{CC} = 15V, $V_{O(P)}$ = 200mV	12	100	-	12	100	-	-	-	-	μA
Differential Input Voltage	$V_{I(DIFF)}$	-	-	-	V_{CC}	-	-	V_{CC}	-	-	V_{CC}	V

Note:

1. This parameter, although guaranteed, is not 100% tested in production.

Electrical Characteristics (Continued)

(V_{CC}= 5.0V, V_{EE} = GND, unless otherwise specified)
The following specification apply over the range of -25°C ≤ T_A ≤ +85°C for the LM258; and the 0°C ≤ T_A ≤ +70°C for the LM358; and the -40°C ≤ T_A ≤ +85°C for the LM2904

Parameter	Symbol	Conditions		LM258			LM358			LM2904			Unit
				Min.	Typ.	Max.	Min.	Typ.	Max.	Min.	Typ.	Max.	
Input Offset Voltage	V_{IO}	V_{CM} = 0V to V_{CC} -1.5V $V_{O(P)}$ = 1.4V, R_S = 0Ω		-	-	7.0	-	-	9.0	-	-	10.0	mV
Input Offset Voltage Drift	$\Delta V_{IO}/\Delta T$	R_S = 0Ω		-	7.0	-	-	7.0	-	-	7.0	-	µV/°C
Input Offset Current	I_{IO}	-		-	-	100	-	-	150	-	45	200	nA
Input Offset Current Drift	$\Delta I_{IO}/\Delta T$	-		-	10	-	-	10	-	-	10	-	pA/°C
Input Bias Current	I_{BIAS}	-		-	40	300	-	40	500	-	40	500	nA
Input Voltage Range	$V_{I(R)}$	V_{CC} = 30V (LM2904 , V_{CC} = 26V)		0	-	Vcc -2.0	0	-	Vcc -2.0	0	-	Vcc -2.0	V
Large Signal Voltage Gain	G_V	V_{CC} = 15V, R_L =2.0kΩ $V_{O(P)}$ = 1V to 11V		25	-	-	15	-	-	15	-	-	V/mV
Output Voltage Swing	$V_{O(H)}$	V_{CC}=30V (V_{CC} = 26V for LM2904)	R_L = 2kΩ	26	-	-	26	-	-	22	-	-	V
			R_L=10kΩ	27	28	-	27	28	-	23	24	-	V
	$V_{O(L)}$	V_{CC} = 5V, R_L=10kΩ		-	5	20	-	5	20	-	5	20	mV
Output Current	I_{SOURCE}	$V_{I(+)}$ = 1V, $V_{I(-)}$ = 0V V_{CC} = 15V, $V_{O(P)}$ = 2V		10	30	-	10	30	-	10	30	-	mA
	I_{SINK}	$V_{I(+)}$ = 0V, $V_{I(-)}$ = 1V V_{CC} = 15V, $V_{O(P)}$ = 2V		5	8	-	5	9	-	5	9	-	mA
Differential Input Voltage	$V_{I(DIFF)}$	-		-	-	V_{CC}	-	-	V_{CC}	-	-	V_{CC}	V

Electrical Characteristics (Continued)

(V_{CC} = 5.0V, V_{EE} = GND, T_A = 25°C, unless otherwise specified)

Parameter	Symbol	Conditions		LM258A			LM358A			Unit
				Min.	Typ.	Max.	Min.	Typ.	Max.	
Input Offset Voltage	V_{IO}	V_{CM} = 0V to V_{CC} -1.5V $V_{O(P)}$ = 1.4V, R_S = 0Ω		-	1.0	3.0	-	2.0	3.0	mV
Input Offset Current	I_{IO}	-		-	2	15	-	5	30	nA
Input Bias Current	I_{BIAS}	-		-	40	80	-	45	100	nA
Input Voltage Range	$V_{I(R)}$	V_{CC} = 30V		0	-	V_{CC} -1.5	0	-	V_{CC} -1.5	V
Supply Current	I_{CC}	R_L = ∞,V_{CC} = 30V		-	0.8	2.0	-	0.8	2.0	mA
		RL = ∞, V_{CC} = 5V		-	0.5	1.2	-	0.5	1.2	mA
Large Signal Voltage Gain	G_V	V_{CC} = 15V, R_L= 2kΩ V_O = 1V to 11V		50	100	-	25	100	-	V/mV
Output Voltage Swing	V_{OH}	V_{CC} = 30V	R_L = 2kΩ	26	-	-	26	-	-	V
			R_L =10kΩ	27	28	-	27	28	-	V
	$V_{O(L)}$	V_{CC} = 5V, R_L=10kΩ		-	5	20	-	5	20	mV
Common-Mode Rejection Ratio	CMRR	-		70	85	-	65	85	-	dB
Power Supply Rejection Ratio	PSRR	-		65	100	-	65	100	-	dB
Channel Separation	CS	f = 1kHz to 20kHz (Note1)		-	120	-	-	120	-	dB
Short Circuit to GND	I_{SC}	-		-	40	60	-	40	60	mA
Output Current	I_{SOURCE}	$V_{I(+)}$ = 1V, $V_{I(-)}$ = 0V V_{CC} = 15V, $V_{O(P)}$ = 2V		20	30	-	20	30	-	mA
	I_{SINK}	$V_{I(+)}$ = 1V, $V_{I(-)}$ = 0V V_{CC} = 15V, $V_{O(P)}$ = 2V		10	15	-	10	15	-	mA
		V_{in+} = 0V, $V_{in(-)}$ = 1V $V_{O(P)}$ = 200mV		12	100	-	12	100	-	μA
Differential Input Voltage	$V_{I(DIFF)}$	-		-	-	V_{CC}	-	-	V_{CC}	V

Note:

1. This parameter, although guaranteed, is not 100% tested in production.

Electrical Characteristics (Continued)

(V_{CC} = 5.0V, V_{EE} = GND, unless otherwise specified)
The following specification apply over the range of -25°C ≤ T_A ≤ +85°C for the LM258A; and the 0°C ≤ T_A ≤ +70°C for the LM358A

Parameter	Symbol	Conditions		LM258A			LM358A			Unit
				Min.	Typ.	Max.	Min.	Typ.	Max.	
Input Offset Voltage	V_{IO}	V_{CM} = 0V to V_{CC} -1.5V $V_{O(P)}$ = 1.4V, R_S = 0Ω		-	-	4.0	-	-	5.0	mV
Input Offset Voltage Drift	$\Delta V_{IO}/\Delta T$	-		-	7.0	15	-	7.0	20	μV/°C
Input Offset Current	I_{IO}	-		-	-	30	-	-	75	nA
Input Offset Current Drift	$\Delta I_{IO}/\Delta T$	-		-	10	200	-	10	300	pA/°C
Input Bias Current	I_{BIAS}	-		-	40	100	-	40	200	nA
Input Common-Mode Voltage Range	$V_{I(R)}$	V_{CC} = 30V		0	-	Vcc -2.0	0	-	Vcc -2.0	V
Output Voltage Swing	$V_{O(H)}$	V_{CC} = 30V	R_L = 2kΩ	26	-	-	26	-	-	V
			R_L = 10kΩ	27	28	-	27	28	-	V
	$V_{O(L)}$	V_{CC} = 5V, R_L=10kΩ		-	5	20	-	5	20	mV
Large Signal Voltage Gain	G_V	V_{CC} = 15V, R_L=2.0kΩ $V_{O(P)}$ = 1V to 11V		25	-	-	15	-	-	V/mV
Output Current	I_{SOURCE}	$V_{I(+)}$ = 1V, $V_{I(-)}$ = 0V V_{CC} = 15V, $V_{O(P)}$ = 2V		10	30	-	10	30	-	mA
	I_{SINK}	$V_{I(+)}$ = 1V, $V_{I(-)}$ = 0V V_{CC} = 15V, $V_{O(P)}$ = 2V		5	9	-	5	9	-	mA
Differential Input Voltage	$V_{I(DIFF)}$	-		-	-	V_{CC}	-	-	V_{CC}	V

Typical Performance Characteristics

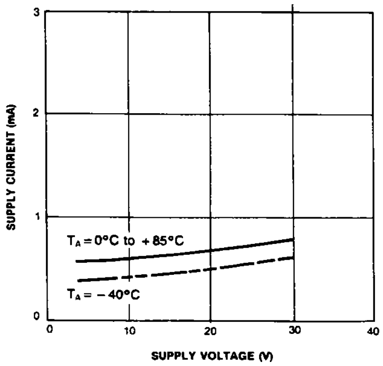


Figure 1. Supply Current vs Supply Voltage

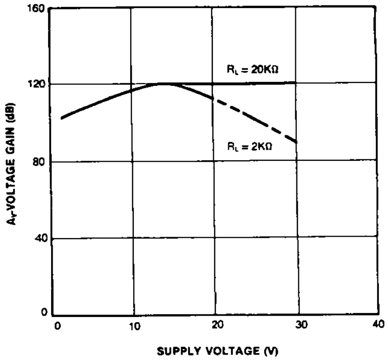


Figure 2. Voltage Gain vs Supply Voltage

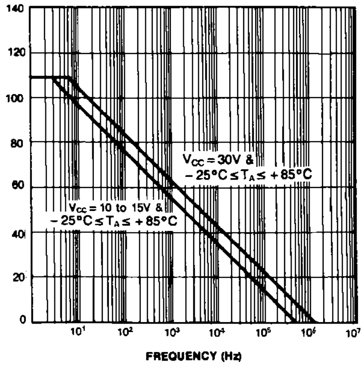


Figure 3. Open Loop Frequency Response

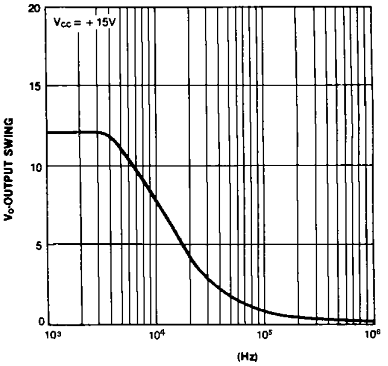


Figure 4. Large Signal Output Swing vs Frequency

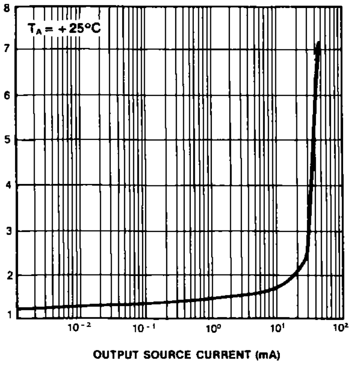


Figure 5. Output Characteristics vs Current Sourcing

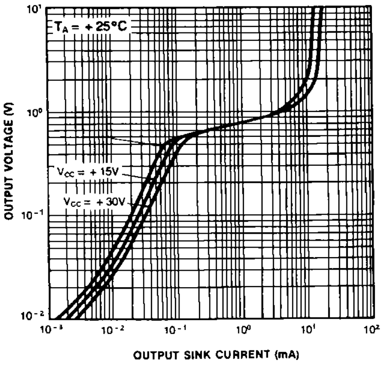


Figure 6. Output Characteristics vs Current Sinking

Typical Performance Characteristics (Continued)

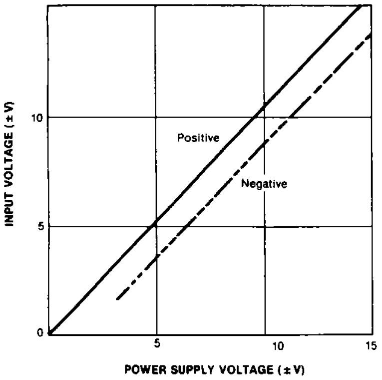


Figure 7. Input Voltage Range vs Supply Voltage

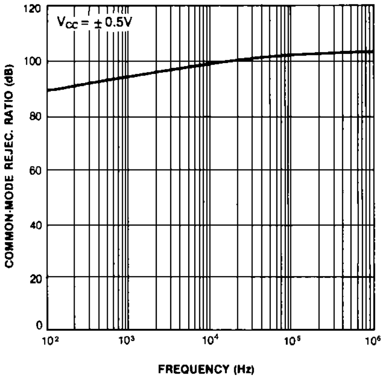


Figure 8. Common-Mode Rejection Ratio

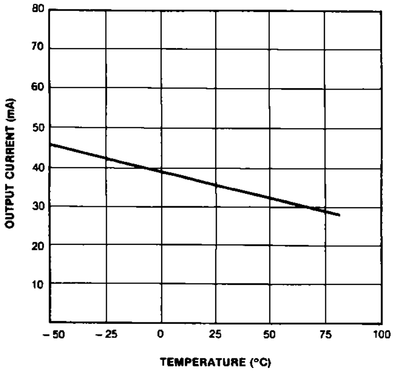


Figure 9. Output Current vs Temperature (Current Limiting)

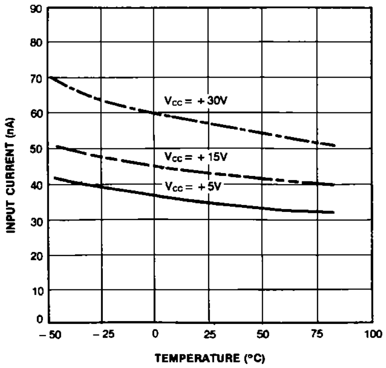


Figure 10. Input Current vs Temperature

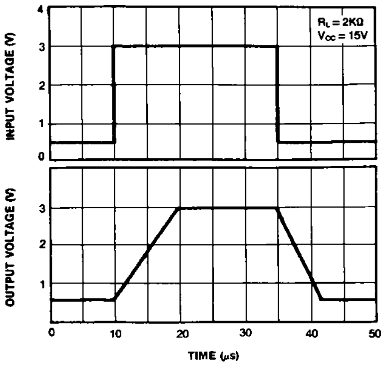


Figure 11. Voltage Follower Pulse Response

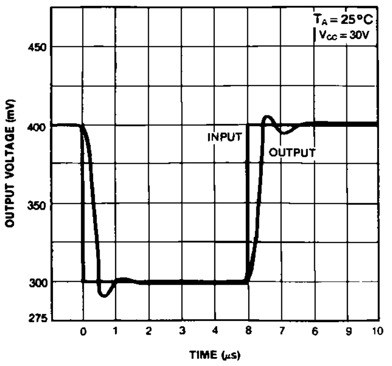


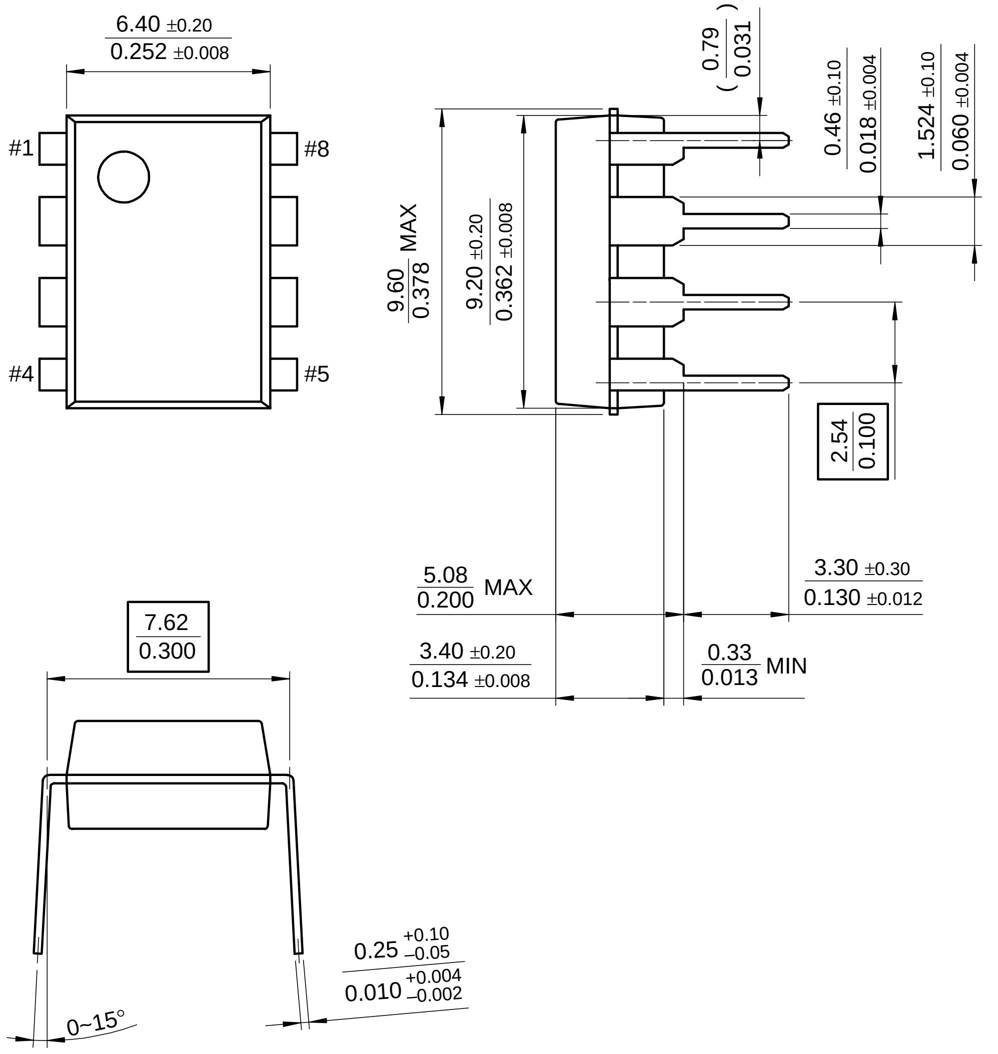
Figure 12. Voltage Follower Pulse Response
(Small Signal)

Mechanical Dimensions

Package

Dimensions in millimeters

8-DIP

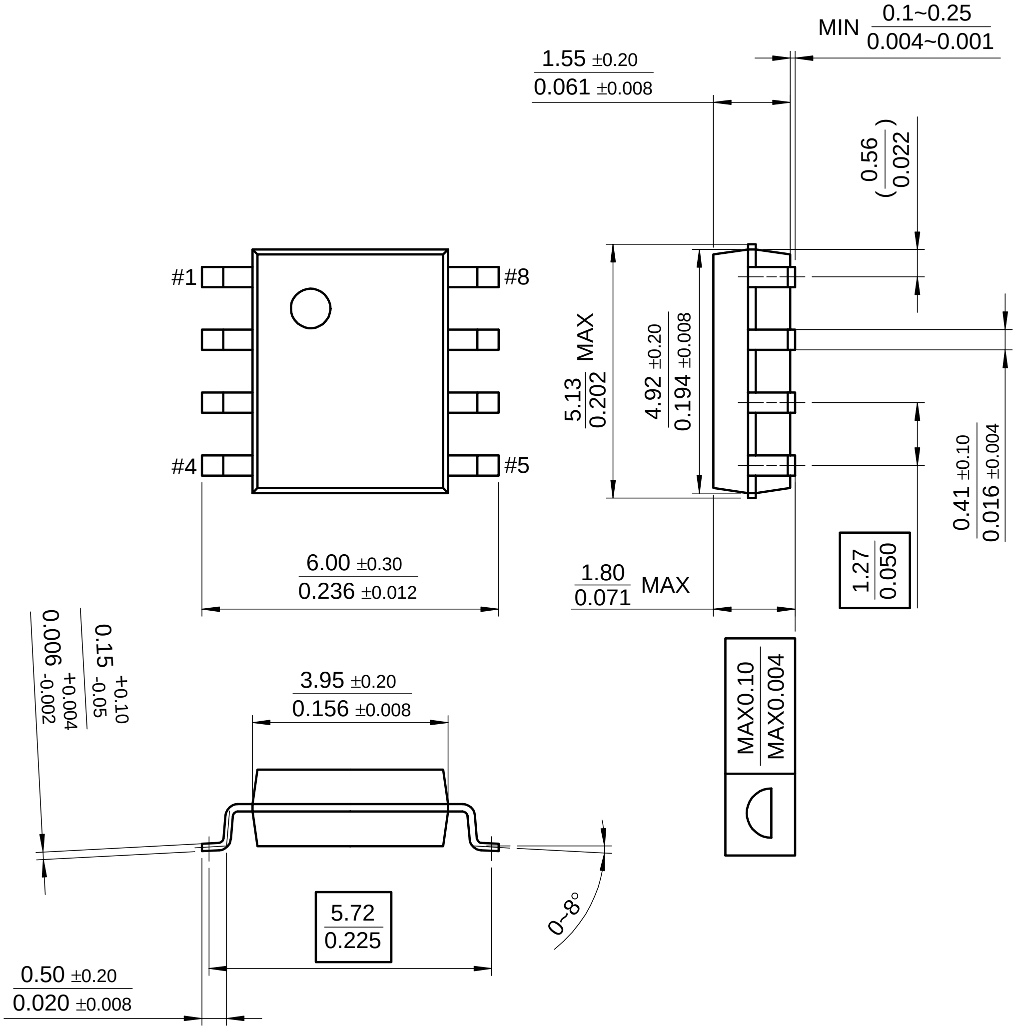


Mechanical Dimensions (Continued)

Package

Dimensions in millimeters

8-SOP



2012

Torque sensor

[**Operation Manual** V4.0]

Thank you for using our patent product---Torque Intelligent Sensor （JCP）！

Address： 118Room East Wuzhong Road Suzhou city
Tel：86-13776058041
Fax：86-512-65725001
E-mail：info@jc-ebike.com

Attention :

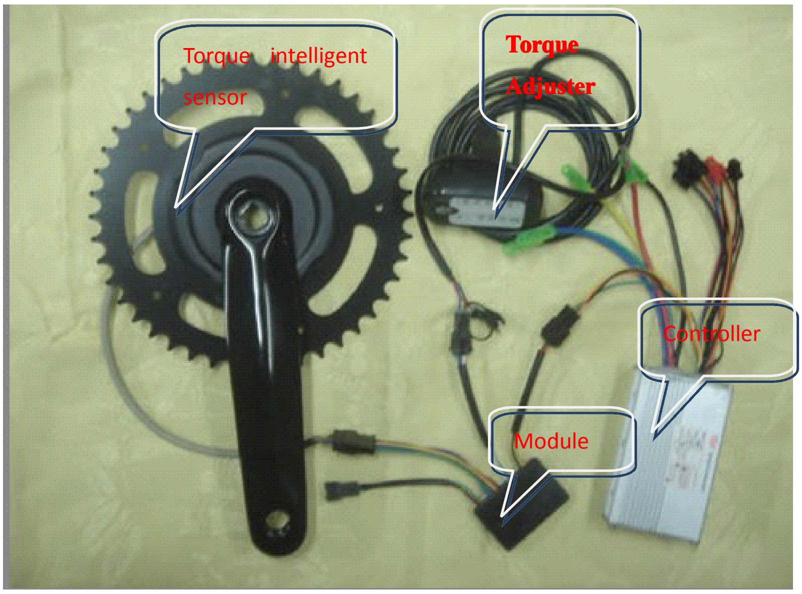
Thank you for using our patent product---Torque Intelligent Sensor （JCP）！

Before your installation of the system, be sure to read instructions carefully.

This product is set machinery, electronics, software, magnetic technology for the integration of high-tech products, high degree complicated, In order to make you try to grasp the method, we particular write the instructions, which you can obtain torque sensor assembly, the vehicle matching debugging, and set and other aspects. We strongly recommend you be sure to read before use this product, , this will help you to better use operation, in order to achieve the ideal effect to your satisfaction.

Item

ONE、Complete set view of component



TWO、 Assembly method

1、 Torque sensor mechanical assembly：

Sensor system components mechanical assembly and ordinary bicycles of crank assembly are same.

Step1. Φ 6 lock pin spread on little threaded glue and then screwing in sensor black mask from center of housing 36mm thread hole.

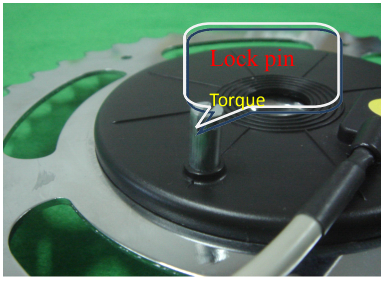
step2. Set the lock plate in B.B. par while installation right five pieces of dishes in turn.

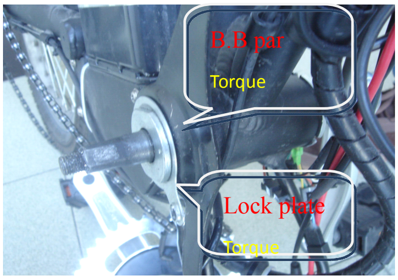
step3. Plug lock pin in turn piece hole.

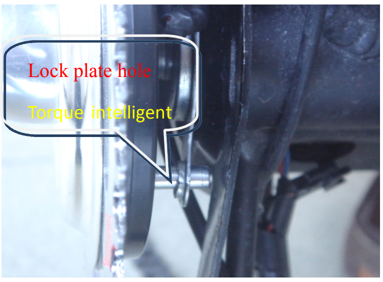
Step4. Fixed the sprocket crank and fasten axial nut.

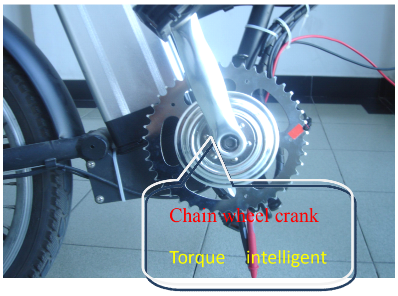
Note：when operating,， If the right axis very short， lock pin hole axis should with the right five pieces of bowl in parallel, in case of sensor molded case with five pieces of bowl of interference.

Installation position as follows diagram：

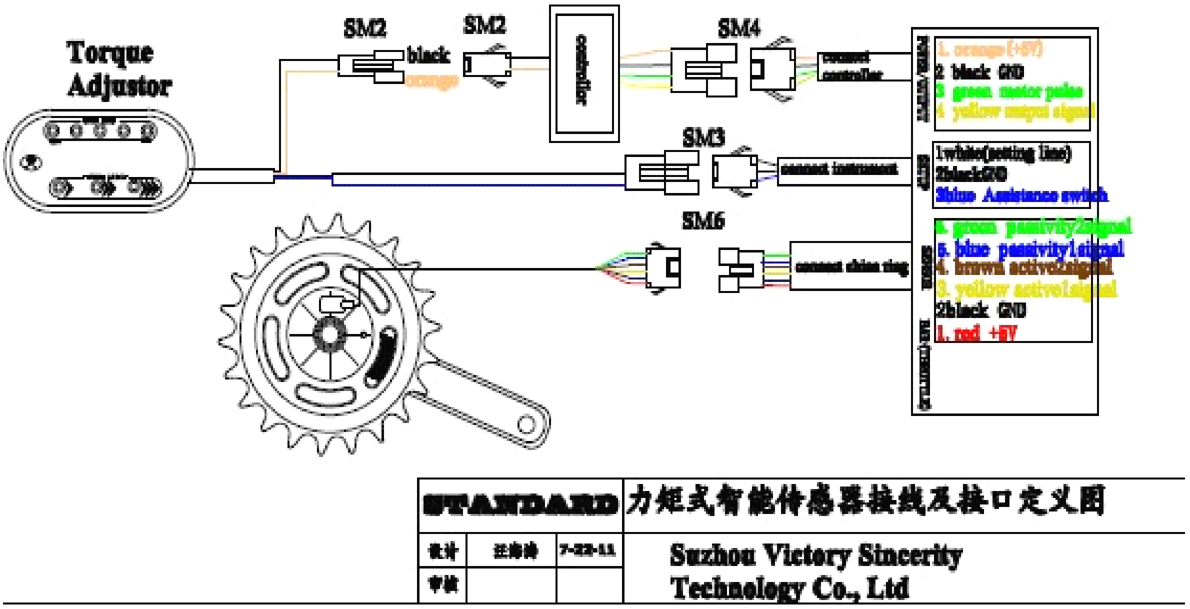








2、Electronic part wiring:



Note: if you have special request，the attached picture shall prevail.

THREE　The vehicle matching debugging method

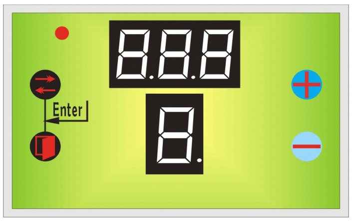
1、Debugging purposes:

I Make sensor and established models in mechanical transmission, controller of matching and motor output perfect coupling, achieve good power output state;
II Compatible with EN15194 and Japan's new JIS requirement and achieved the general purpose;
III Satisfy terminal customer different strength needs.

2、Introduction of the setting device

I Universal setting device was aimed at our company produces the torque type intelligent sensor system design of special tool, through this tool can external adjustment sensor of 8 items output parameters.

II Instructions functional specification:



A digital tube 1-8 respectively show 8 parameters, three digital tube corresponding eight parameter values;

(Setup device)

① **PAS output direct voltage weight**——Refers to the sensor work output the direct signal voltage size (related to vehicle wheel diameter and motor output power and such factors, also the direct component of vehicle dynamic output),

Set limits：0.2V ~ 2.5V (^{X}10)。

②**PAS Start speed**.——Refers to achieve the torque output corresponding voltage value the time process quantity. Numerical smaller, namely the time achieve torque output voltage will be longer, the start-up more slowly；Conversely, start-up more faster；Set limits：1~50。

③ **low-grade torque amplification coefficient** -low-grade strength size.
④ **midrange torque amplification coefficient** - midrange strength size.
⑤ **top-grade torque amplification coefficient** -top-grade strength size.
⑥ **outage time**——Refers to the foot stop start to motor without output delay time quantity, the unit output for milliseconds, like a 200 namely 200 milliseconds blackouts, outage time for too long safety poorer, outage time too short low-speed ride will have jitter and with strength slightly smaller.

⑦**PAS attenuation coefficient**——（This parameter setting only against Japan JIS） JIS standard: when 10km/h motor power began to decrease, speed per hour :10km/h~24 km/h， Motor power with the speed of increase decays until is zero. The regular parameter is 100,greater than 100 it will tend to gently(attenuation weaken, until 200 un-damped, but it will outage 24km)，less than 100 it will tend to slope(attenuation strengthen).This parameter relevant to motor efficiency characteristic and controller characteristic and so on, the setting should be according to the actual situation.

⑧**Speed limit parameters**：collect motor hall signal, this parameter is refers to the motor one round of hall pulse count N and wheel diameter Φ (unit: inches) ratios： namely（N / Φ）X100。For example N=44;R=26 inches，the ratio is 1.69。So for setting is 169，The number higher, cut-off sooner. Use the parameter adjustment carloads of highest speed, reach to speed limit function. such as 24km/h、25km/h and so on;

Note： Set parameters for reference only, can according to different strength effect to adjust strength state.

Export to Japan (JIS standard) Generally adopt 24V

item models	1	2	3	4	5	6	7	8
16"	115~130	80~100	45~65	120~140	200~240	105~120	100±30	275
20"	,,	,,	,,	,,	,,	,,	,,	220
22"	,,	,,	,,	,,	,,	,,	,,	200

24"	„	„	„	„	„	„	„	183
26"	„	„	„	„	„	„	„	269

Export to EN（EN15194)　　Generally adopt 36V

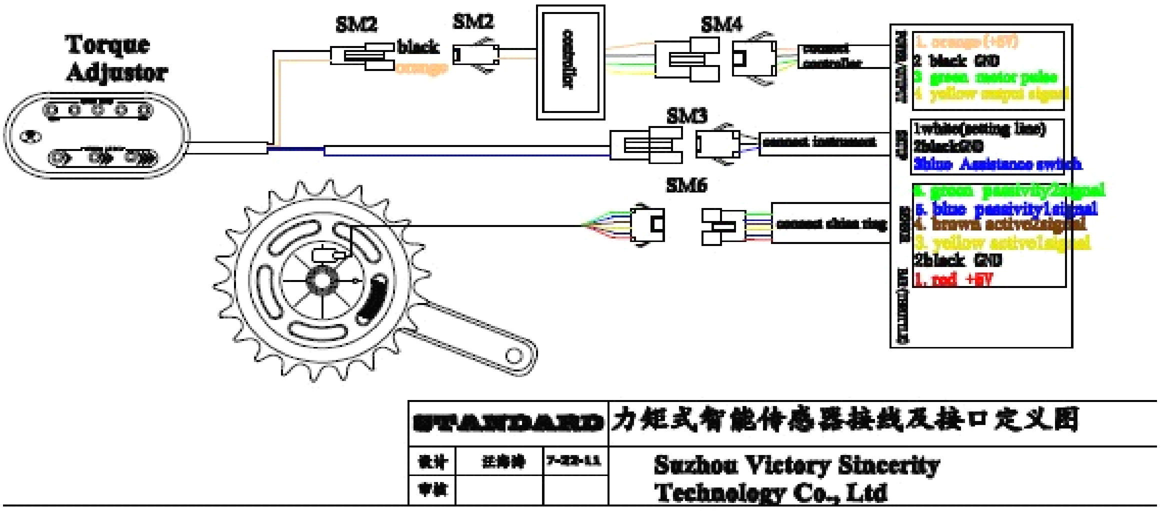
item models	1	2	3	4	5	6	7	8
16"	140	20~30	30~80	120~140	180~240	120~250	000	275
20"	150	30	„	„	„	„	„	220
22"	160	40	„	„	„	„	„	200
24"	170	50	„	„	„	„	„	185
26"	180	60	„	„	„	„	„	169
28”	180~190	60	„	„	„	„	„	157

Note: As current mode controller, the different voltage lead to different power due to the matching: P=U*I, in addition, the parameter is also different according to the different limited current, electric efficiency, transmission ratio and battery.

3、Setting process

(1)Connecting methods ： SM4 of controller connects with SM4 of PAS module ， SM3 of PAS module connects with SM3 of setting device, SM2 of setting device connects with SM2 of controller.

Specific wiring as follows:



Picture 2-1

(2) Operational steps ：

The first step　Enter into parameters adjustment state:

Pick up good line, then open the power supply. now setting device a digital tube digital circulation increase shine, while pressing left 2 buttons into parameter setting status,

The second step parameter setting: Enter parameter setting state later, a digital pipe display 1，at this time through right two keys to all three digital tube namely the first term parameters———PAS output direct voltage weight adjusted, the up key to increase, below key to decrease (Each time you press the three digital tube ±1, pressed continuous increase, 500 corresponding to 5V); Confirm the number, press left-down keys are being sure to save, the first parameter adjustment finished,

Press the upper left button to enter the next parameters adjustment, the remaining parameters adjustment method by analogy.

Remember: adjust each parameter, must press left-down key sure to save! Otherwise modified parameter adjustment is invalid!

The third step Exit parameter setting status:

And enter setting state operation method is same, meanwhile pressing left two keys exit parameter setting status, now setting device set state a digital tube in circulation increase, in turn, three digital tube display after setting value.

Fourth step parameters lead-in: the last step is indispensable step!

press the left below key ordinal turn the setting parameters into PAS module ，now setting device a digital tube numerical fast in turn skip， this process ended, PAS module work lights flashing rapidly, display parameters import PAS module process success.

Step fifth Cut off power supply, disconnect setting device, complete the whole parameter setting process.

Basic set skills:

1 Adjust riding assistance size:

Divide kind of case：

(1) if riding slow feel power is too small, increase the first parameter；if slowly ride feeling feet trample when "very empty" like speed sensor, reduce the first parameter；

(2) if riding feeling slants "wood" or uphill assistance slants small, increase 3, 4, 5 parameters and whole scale basically unchanged;

2 Adjustment start-up assistance size: start slowly, no outbreaks feel, increase the second parameter,

Note: each parameter adjust accordingly according to different controllers and models. These setting skills can meet try driving or 90% of the requirements of customers, if you have any other special requirements, please specify, can be settled through friendly negotiation

Four Normalized Settings

1, set purpose:

Eliminate due to various factors (replacing sensor module, etc...) bring about electromagnetic Angle matching errors

2, set premise:

Replace torque sensor module, sensors and a PAS module has not been paired or when the maintenance and replacement operation, normal products without this setting.

3, set basis:

Between Sensors and PAS module need parameters matching can guarantee system consistency.

4, procedures:

(1) The connection method: normalization set connection as shown in figure 2-1 shows:

(2) **Operation method**: open the power

① press the upper left key and lower right key at the same time enter into the setting mode, three digital tube show: "101" ,namely you enter into this mode.

②Then press left down button, indicator light LED : fast flash—light out—fast flash（the indicator light just fast flash when setting the parameter）,now you can set without any strength, turn the crank and chain wheel some circles clockwise, the indicator light on, then the normalized settings finished.

③Finally press the upper left key and lower right key at the same time exit this mode.

FIVE Matching and Selection of Controller

There are following requirements about controller in order to attain well effect of riding and matching:

1. The input and output should demand keep linear, so we suggest adopt current mode controller, mean the signal of the input voltage proportional to output current.
2. Adopt the faster, no slow start, no delayed controller so that reach the good adaptability among input and output.
3. Adopt the controller has high efficiency and a good match with the motor to strength matching effect and saves the electricity.
4. To achieve good effect of zero start, had better use the hall and high-speed motor.
5. Try to choose brushless motor in order to promote the strength characteristics under low current.
6. Try to use motor below 250W.

Conclusion: it is the best choose to use the current mode sine wave controller with hall.