Lecture -22
Design of Speed Control of DC Motor: Circuit Explanation

Hi, welcome to this particular module. In this module we will concentrate on the, practical aspects of the DC Speed Controller. In the last module if you remember, I have discussed the details, quickly. Right? About, how we can design, DC speed controller and in this module, I'll ask my TA, to further show you the experiment part, he will discuss a little bit about, why what is the importance of that circuit? As we have earlier prepared it for you guys. And if you have any questions, at the end of the module, you can always ask us through forum, I'll ask now, Citarum to take it over. Now, we will discuss about, the implementation of speed control of a DC motor using operational amplifier,

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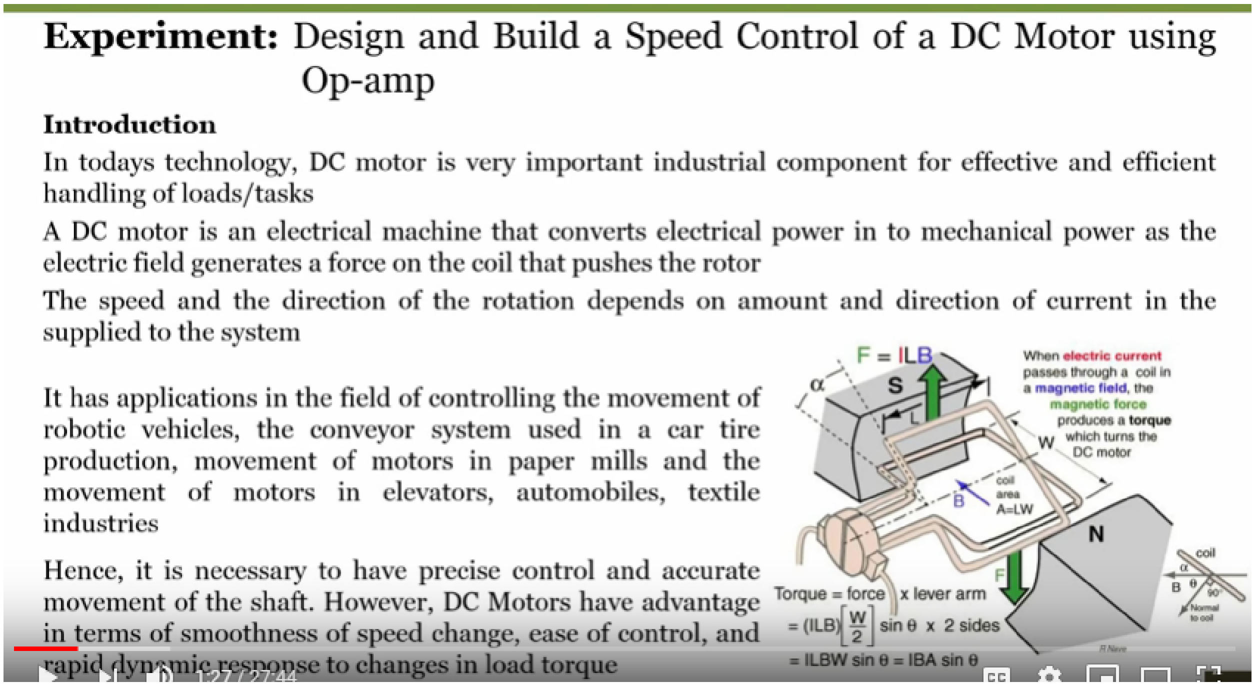

as Professor I already discussed in the last module, the complete working of speed cont, DC motor.

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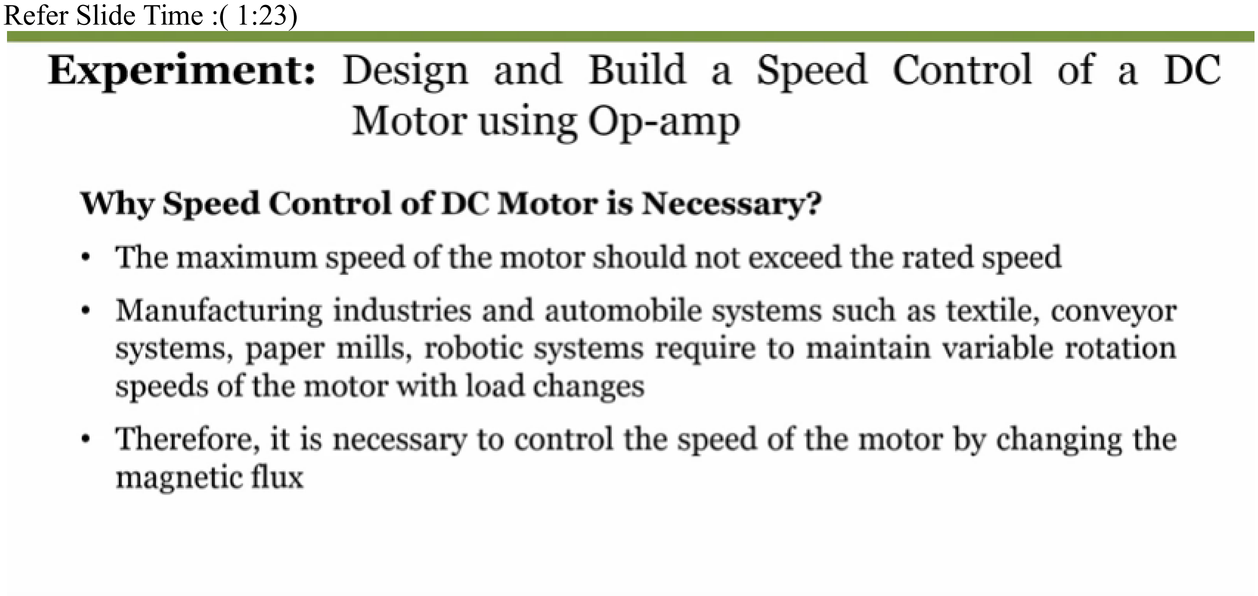

And he has also discussed about, why it is required

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Experiment: Design and Build a Speed Control of a DC Motor using Op-amp

How Speed Control of DC Motor is Implemented?

1) Simplest way to control the speed of motor is by using a variable resistor in series with the motor. However, this method dissipates excess energy as heat (This method is called Armature Voltage Control)

2) Flux Control: In general, speed of the motor is inversely proportional to the flux. Thus, by decreasing flux and speed can be increased vice versa. To control the flux, rheostat is added in series with the field winding. Adding more resistance in series with the field winding will increase the speed as it decreases the flux. So, the field current is relatively small and hence I^2R loss is decreased. This method is quite efficient but it can control the speed above the based speed

and how the speed control has been implemented?

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Experiment: Design and Build a Speed Control of a DC Motor using Op-amp

Aim:

- The major task is to control and maintain the speed of the DC motor using op-amps (Analog electronics) as per the user requirement. This requires a sensing device to measure the RPM of the motor. Generally, RPM is measured by using the existing encoders. However, the output of these encoders are digital. Therefore, it is necessary to design a signal conditioning circuit for the sensor to convert the frequency of pulses obtained in to analog which can support by the system
- The control action needed to bring and maintain the speed (RPM) of the motor to the desired set point were obtained by designing a basic controllers with an objective of minimizing error for settling

Objectives:

This project consists of the following major objectives as listed below:

i. To implement a circuit for converting the digital pulses from encoder to analog variable signal
ii. To implement a controller to maintain the temperature of the transistor to the required set-point

So in this module, what we are going to see is that, we are going to develop a signal conditioning circuit, as well as, a controlling unit, in order to control, the RPM of a motor. But, the complete case today is building using, operational amplifiers. So, the major task of this particular session, this particular case study is that, first we will develop, the signal conditioning circuit that is required, for a sensor, to convert the digital pulses into the analog output. And to map with respect to the, output of encoder to, the input of set point. Then since we are driving the motor by using operational amplifiers, as op-amp cannot directly provide enough current, in order to drive the motor, we also have to design a driver circuit, in order to use the output of operational amplifiers, as well as, to run with the help of operational, then the output provided from, the operational amplifiers. So, first we will discuss about, how exactly the driver circuit looks like? Then, what is an importance of having a signal conditioning circuit for the sensor? And how exactly we are going to convert, the digital pulses that we are getting from the encoder, to the analog, linearly varying and output that match with respect to the input of your set point. Then later on, we will see, the working of each controllers, starting from on-off controller, P controller, PI controller, then we will also enter, into interface, all the blocks, all the subsystems that we have, designed in order command, in order to make a closed loop control system, will integrate everything and we will see the demonstration of working of each controller, with respect to different set points that, they that we give it. Right?

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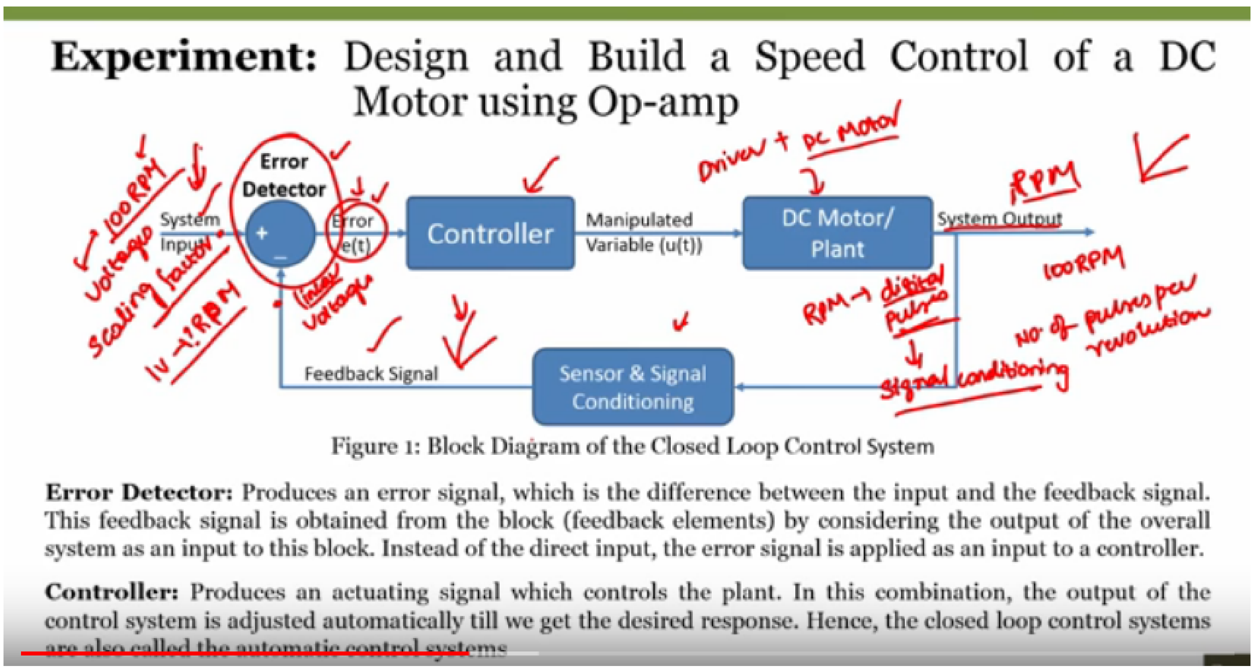

So, this is the complete overview of this demonstration. So, as professor already discuss about, the closed-loop control system. So first part, what we have to do here is that? We have to design this particular block, which is an error detector, we will see, how exactly we do that, error detector using operational amplifier. Then we will discuss about, the importance of having different controllers, how we do using operational amplifiers. So, basically if you look into this closed loop control system, whatever the user require, so in this case, you say require in the sense, what RPM the motor has to be rotated that, we should know. So, if I if a user wants to know about, if a user wants to, control the RPM of the motor to be somewhere around, 100 rpm. Right? So, the, the input given to the system, should be of the required output that user is, intended to make the motor to rotate with. But, as we are designing again, complete analog control system or electronic module, so when we you in terms of an RPM, it is very difficult for a system to understand, the units of RPM. So, we require whatever the input that is, provided to the system should be in terms of voltages, in terms of voltages. So, but how do we convert this voltage is to rpm, so we should always have to think about, scaling factor.

So, based upon the voltage that we provide, based off of this choose in scaling factor, which gives you the information about, what voltage corresponds to RPM? So, based upon that particular voltage, system will understand that, the motor, the user is intended to drive, the motor at that particular RPM. So, similarly when you see the output from the error detector, the output from the error detector, which is nothing but the difference, between the system input to the feedback signal, feedback signal in this case is nothing but, the output from the sensor. Right? So, the difference between these two is nothing but here, error signal, the output that we are getting from the sensor, should also match with the input scaling factor, which means that, this particular mapping factor. But, we are not very sure, whether the sensor, can match with this or not. So, first we have to understand, understand about, how the sensor is, the output of the sensor is how can we map with respect to, so by designing a signal conditioning circuit, we have to map, the output of a sensor, with respect to the input quantity. Then both will be in of same units, then by using a simple difference amplifier, we can make the difference between the two inputs and we can generate an error signal. We will see, one by one, then that will be passed through a controller, then the output of the controller which is nothing but a manipulated variable, will be given, either directly to the plant, sometimes by using a driver circuit, in our case since, the plant cannot drive, directly drive from the motor output, the motor cannot directly drive from the controller output, we require to use a driver circuit. So, in this case, we need a driver circuit. So drivers the DC motor our plant, contains both driver circuit, as well as, DC motor. Such that, such that, whatever the output it use, from the controller, the same output will be applied, across the DC motor. But, the current will not be taken from the controller, it will through from external power supply. So, we will also, see how exactly the design that we are going to do, in order to make the motor to work for, particular manipulate available. Then, then system in this case is a plant, will rotate at that particular rpm. But, how do we generally understand, at what rpm the system is rotating. So, we require, since rpm is in another word of my, another physical quantity and the complete system also requires electronic unit, what we have to use is that, we have to incorporate a sensor. So, there are different rpm sensors available, in the market.

So, either rotary encoder, are hall of basin's rotary encoders. So, so many rotary encoders are also there, so by using, rotary encoders we can convert rpm, by interfacing it to a motor, we can convert the RPM of a motor, into digital pulses. But, these digital pulses entirely depend upon at, what rate the RPM the motor is rotating with? And how many number of pulses that you are getting per revolution? So, one important thing that, we have to understand about the, encoder is result. How many number of pulses that encoder use, per revolution that is very much important. once we know that, then, then whatever the output we get from, out of digital pulses, gives an indication of an RPM but, our system require the output, also in terms of voltages, the two linearly proportional to the change in the RPM. So, that it map the output of this particular value, should match with the this value, in terms of units, not in terms of magnitudes. So, that both can be easily comparable, but in this case, these distal pulses it is very difficult. So, what we have to do is that? We have to build a signal conditioning circuit. So, such that, this signal conditioning circuit, which is the output of the sensor, will be interfaced to the signal conditioning circuit, which converts, the digital pulses into linear voltages. So that linear, why I am saying linear because, any change in the RPM, linear change of RPM will would result in linear change of output voltage, it should always be same fashion. Right? And not only that, not only in the linear fashion, we should also map, the sensitivity factor or scaling factor of the system is, equal to the since a, scaling factor that we are, mapping factor basically that we are setting for the system input. Right? So that means, when you look into that, there are so many number of subsystems that we have to design for this particular, for this particular case study. So, once a subsystem would be, for error detection, once the subsystem for the controller and in this case, one another once of another system, subsystem is your driver to drive the DC motor.

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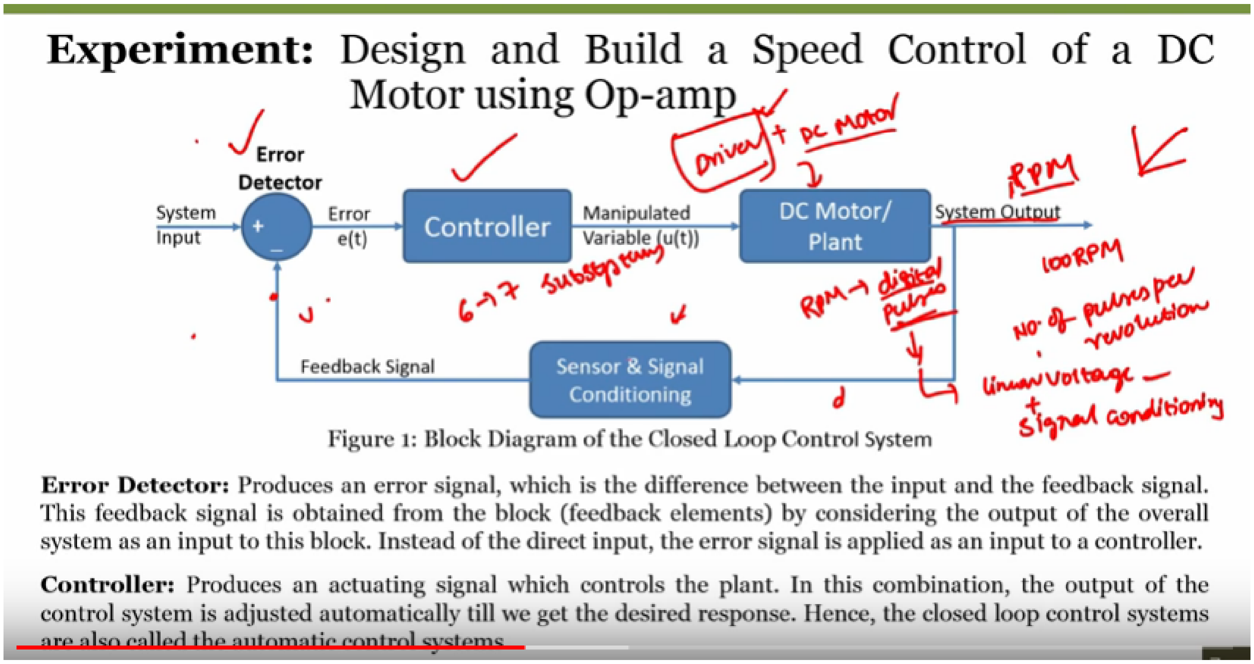

Then one signal conditioning circuit, to convert digital pulses, to linear output voltage, digital pulses to linear voltage. Then, if this linear voltage mapping factor is not matching with, our system input mapping factor, again another signal conditioning circuit is required, to map with. So a total of, one, two, three, four, five, six, seven, six to seven different subsystems, we will be independently designing, then we will verify, the conditions, the working of each every each and every subsystem, whether it is working as per our requirement or not, then we will interface one by one and sometimes during the interface, there are chances due to, because of, loading effects there are chances of, not functioning as the requirement. So, we also have to see any interfacing error that occurs, then we have to solve for that interfacing errors. Now, first we will start with, error detector. Okay?

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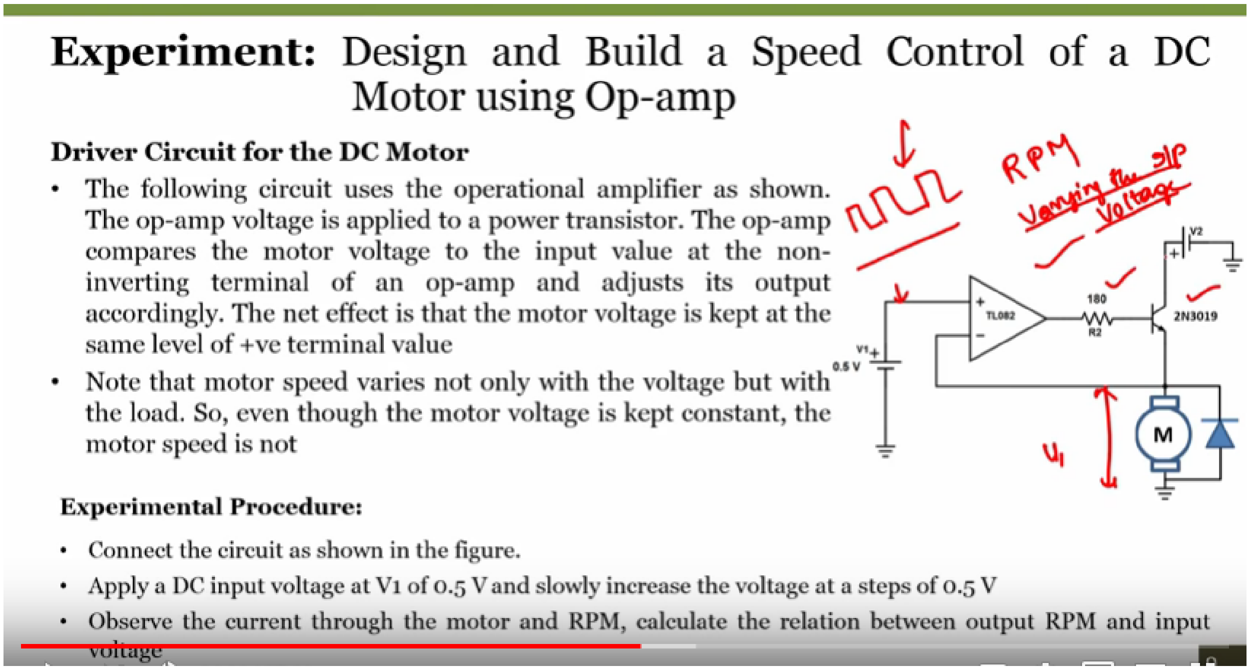

Now, now we will see about, the driver circuit for DC motor. So, as you remember, in case of a DC motor, if I want to change an RPM, two important things that we have to consider is that, one is by varying the input voltage. Right? So, changing the magnitude of input voltage, also changes the RPM of your motor, as well as, changing the current, by controlling the current through the motor, can also change the motor rpm. But, wearing the input voltages is quite easy, either by using, microcontrollers we can change the input, we can vary the input voltage and it is easy to derive it. But, in case of varying input voltages, we cannot directly interface it to a motor, because the motor requires a little higher current, whereas the microcontroller, cannot provide you the, enough current to drive the motor. So that's what we require to you go with it, driver circuit. Now, even in case of varying, even in case of providing, different magnitudes of input voltages to the motor, there are two ways, one by using a pulsating ,as we as, professor already discuss in the class or you can use DC. So, this particular driver circuit whatever I am going to discuss right now, whatever I am going to, you knows design and demonstrates you, does not require a varying signal. But, rather than providing a variant signal, we can also provide it direct to DC voltages, as at the input of the system. So that any DC voltage provided at this, particular positive terminal. Right? The motor, the output voltage across the motor, will also be the same, as the input voltage. But, how exactly it work, how do we know that, the voltage will be the same. And how exactly, the importance of each and every block that we are using it here, everything will discuss, one by one now.

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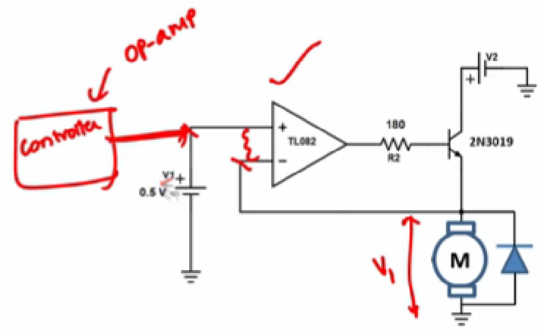
Experiment: Design and Build a Speed Control of a DC Motor using Op-amp

- Explanation:



So, when you look into the system, recall of our working of, our operational amplifier, since our intention was to use an operational amplifier, at each and every aspect of the design. So, when you recall into operational amplifier, few important properties, one important property is that, the positive terminal, virtual drone concept which is nothing but, the difference between the two terminal voltages should be always same. But, this case will be valid only, if the operational amplifier is in negative feedback system. Now, in this case if you see, the when we say, a negative feedback, when the output of operational amplifier is connected, to the negative terminal of an our operational amplifier, then we say it is negative feedback configuration, even in this case, if you see the output of an operational amplifier is connected to, a negative but, through some resistor, transistor and the emitter of the transistor to negative, no matter what with so many other, components we have interfaced the output of, operational amplifier to the negative turn .So, still it is in negative feedback loop.

So, because of this negative feedback, as we know that, one important virtual bias concept, which will convert, which will guren concept what it says, so the, whatever the input voltage that we apply at the positive terminal of an operational amplifier, it also maintains, to have the same input voltage, at the negative terminal of operational amplifier. As a result, when we apply V1, of different magnitudes at the positive input terminal, the voltage across the motor, will also be the same. So one aspect is, whatever the microcontroller, so that means, this particular input, we are getting from a controller, whether it can be a digital controller, like a microcontroller or microprocessor or we can design our own, op-amp based PPI, PID controllers or on-off controllers, in order to drive this. So, since our intention was to go with an operational amplifier say, when we are using a mic, op-amp based controllers, say especially up P, PI controllers. So, when this controller gives a manipulated variable that output, will be directly connected to the positive terminal of, our operational amplifier.

So, as a result, whatever the controller is giving the voltage, the same voltage will be even at, at the motor terminals. One terminal of a motor is already connecting to the ground, so this particular voltage is also equal to v1. But, what about the current that is required ,to drive the motor. Right? Whether is this good enough to drive the motor, everything we have to check it. But, before checking everything, first we will understand ,how exactly this works, where the current is being provided to the, to the motor. So, one aspect of voltage, it is clear that, the voltage across, the motor will be the same as, the input voltage that is connected at the positive terminal of an operational amplifier. Since the output voltage, since the output of operational amplifier is connected to through a resistor, through a transistor. So, in this case we are using 2 N3019, it is not compulsory that we have to always go with 3 0 1 9, either we can go with the 2 n 3 055 or even BC 5%. But, only thing is that, it should match the requirement. What is the requirement here? The one thing is that, the motor rating.

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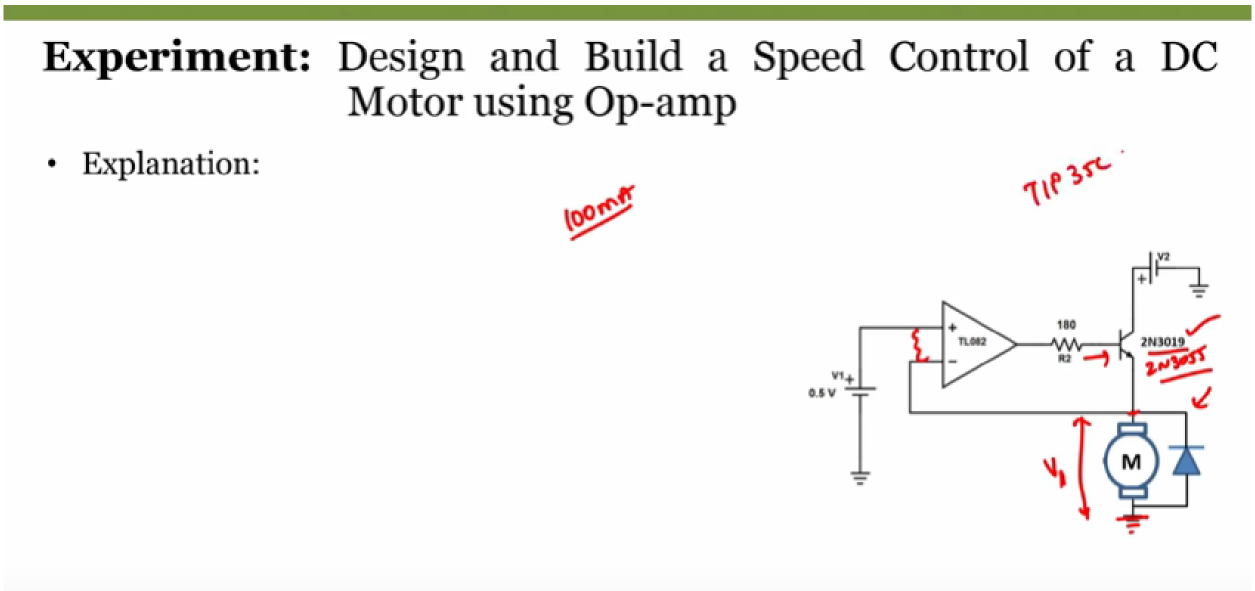

So in this case, whatever the motor that we are using ,requires a minimum of, say 100 milliamps current. So, the transistor that we select, should able to provide, our should, should work for at least 100 milliamps of current. Right? That is one thing, then, then it should not damage, ah, another thing is the by a base current. Right? So, this these things are very much important, when we are selecting any electronic components, so in this case, as we require only 100 milliamps, 2N3 0 1 9 support for 100 milliamps of current. But, if your motor is a little higher rated, which requires more than amps of current, we can go with 2N 3 0 55, which can support up to 10 amps of current or tip 35C, which can work up, to 1.5 to 2 amps of current. So please, look into the datasheet, for further information about, different properties, electrical properties of transistor.

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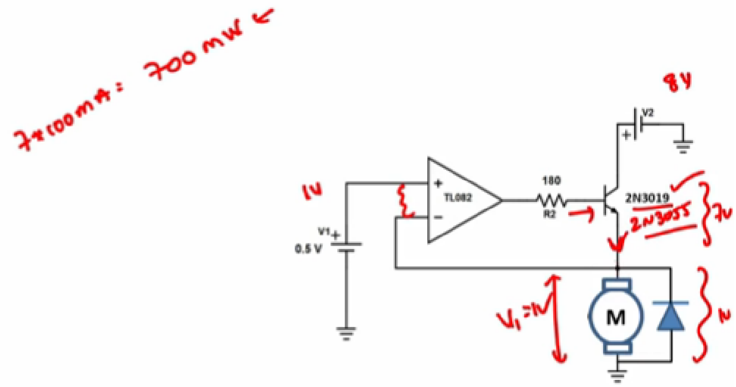
Experiment: Design and Build a Speed Control of a DC Motor using Op-amp

- Explanation:



So, so what happens now. So since this particular voltage is, of v1 say for example, say the input voltage v1 that we have connected is of one volt, this particular value is also equal to one volt. So, as a result, suppose if the input would, if this voltage connected is of eight volt. So, one volt will be dropped across this value and remaining seven volts, will be dropped across this transistor. But, the problem would be, because of seven volts drop. And because of 100 milliamps of current, the total power, the total VAT is dropping across, the collector and emitter terminal will be, seven in two hundred milliamps, which will be seven hundred millions, mill watts. So, total 700 milli watts of power, will be dropped across the collector and emitter and there are, chances of, slightly heating it. Right? And not only that, the current flowing through, entirely depends upon, the current the motor is being accepted too. So, as a result, to limit our current, what we can also do is that, instead of directly connecting the emitter of a, transistor to directly to the motor.

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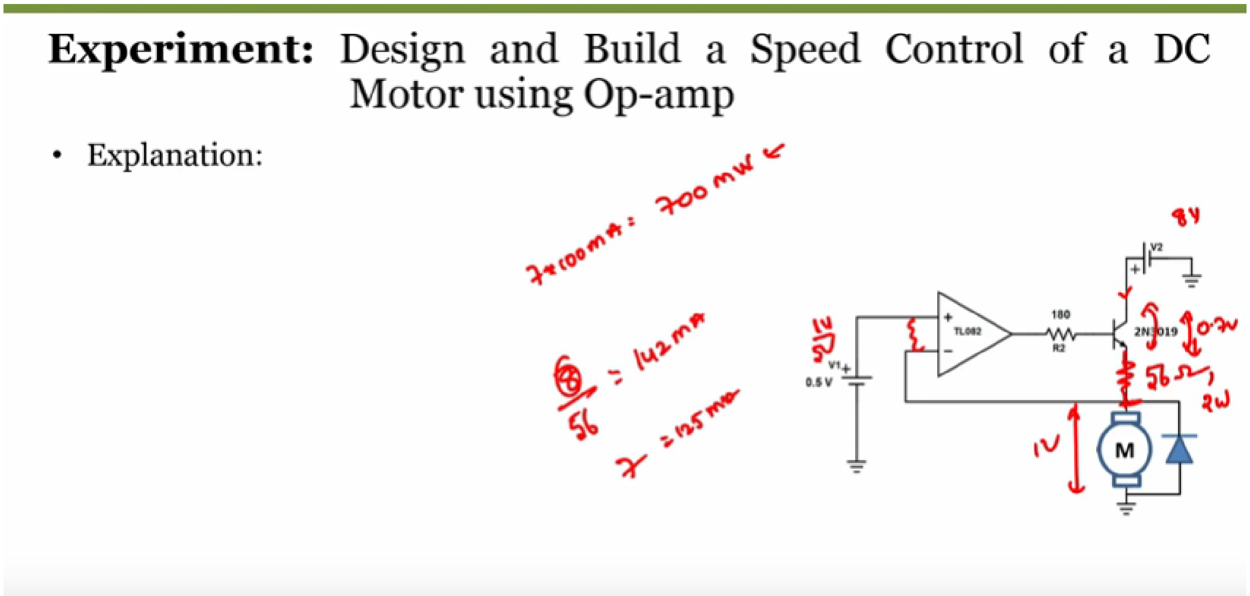

In practical, I have used, a resistor of 56 ohm, of to whack such that, such that, the maximum current, this can allow will be, 100 milliamps of current. So, if you see, so we if you are applying 8 volt, so the maximum voltage that we are using is a 5 volt and the minimum say, zero volt. So, total will be 8 volts, drop across this and this requires, 0.7 volts to switch on, minimum of. So, 8 divided by 56 if you see, the value will be somewhere around, 142 milliamps, so suppose if there is some voltage drop, say 1 volt, so total drop will be in this case 7, 7 divided by 56, 125 millions. So, no matter what, no matter what, at what voltage that we are at, the maximum volt is, the maximum current that will be, will be at the collector or emitter ,will be very less value. As a result, the power across the collector emitter will be smaller, there are, the chances of heating the transistor will also be smaller. And another resistor, which we are using it here, which is of 180 ohms, the importance of this resistor is, to limit the current flowing through the base, of base of transistor. Of course, TL802 or op amp, any op amp can provide up to maximum of 20 milli amp, anyway this is really smaller. But, in case when we are directly connecting it, some other thing, it should not damage the transistor, so in order to limit the current flowing, through the transistor, by using some current limiting resistor, maybe not to be 180 ohm, so we can go with 220, 270 some value. So, that the current will should be smaller. So two resistors, one to twenty, other one, 56 ohms. But, in this case we require to have a, little higher VAT is it at least one vat. So that, this transit this resistor will not heat. So as a result, whatever the voltage that we apply at the input of positive terminal, the same voltage will be ,even across the motor, so the motor will start functioning. So, the purpose of this, this diode is called, 'Freewheeling'.

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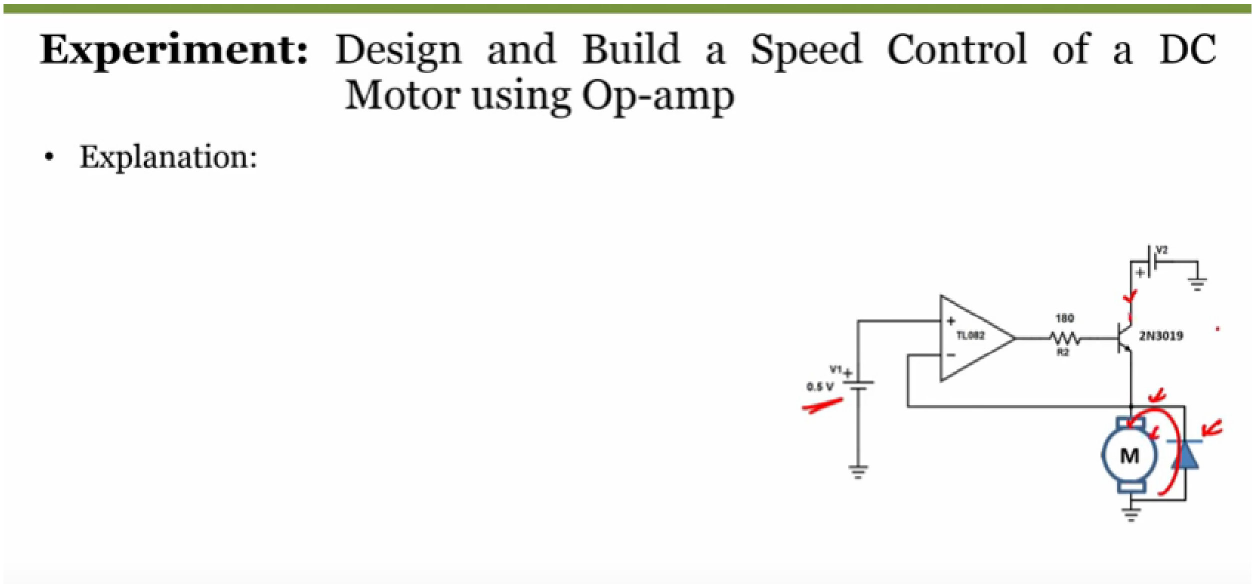

So, when the motor is not working. So, whatever the energy is being stored, it should dissipate, so in order to when, when the motor is off, whatever the energy stored, will be dissipated across the, the coils inside the motor. So that it will not damage the transistor. So, this is called, ‘Freewheeling’. So these are the component that we are using it here.

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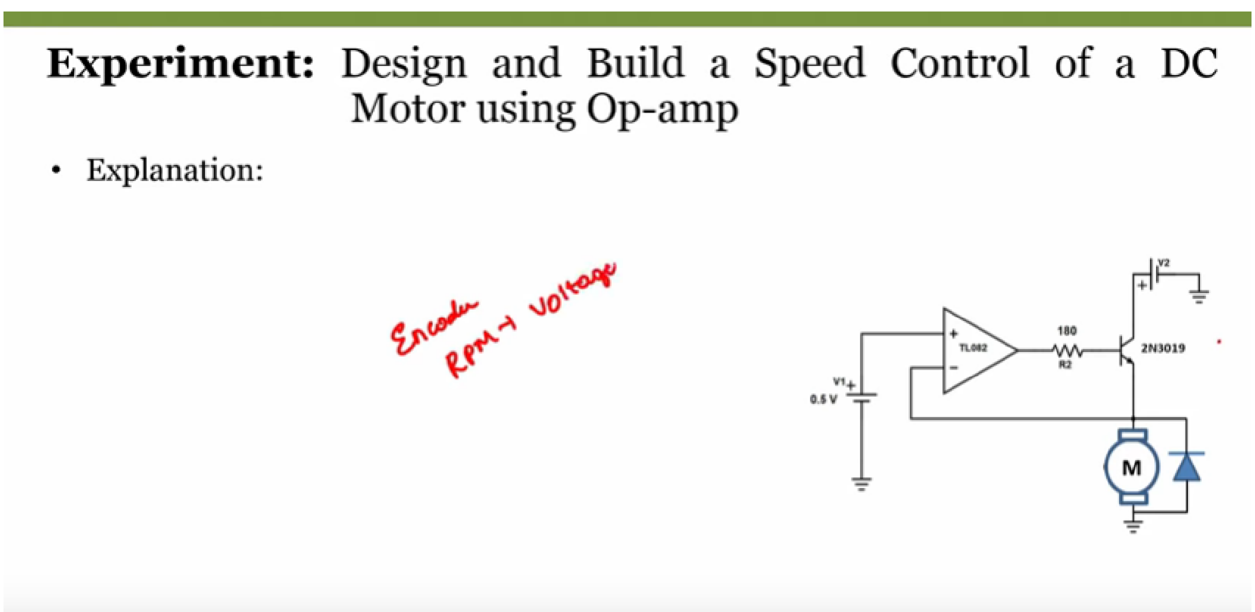

Then we, then we have to use, an encoder or a sensor, to convert this rpm into some voltage.

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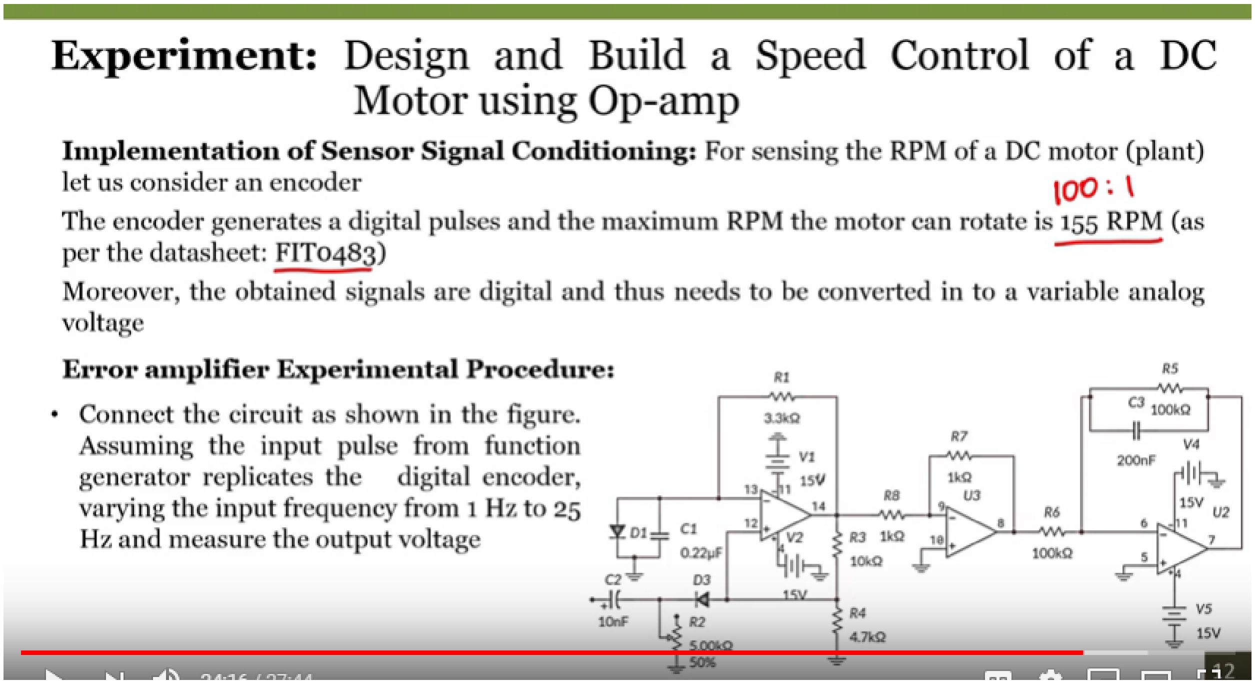

So, for that particular case, we are using encoder, so the motor that we are using, has an integrated with an encoder, for further details of the motor ,we can look, you can look into the datasheet FIT 0 4 8 3. So, the motor this is a micro gear motor, which can rotate up to a maximum of 155 rpm, because of the gear ratio in available. And the gear ratio is of 100 is to 1, so otherwise if there is no gear, the motor will be rotated to somewhere around, 14, 15,000 rpm. Since there is a gear ratio, the final rpm will be 155.

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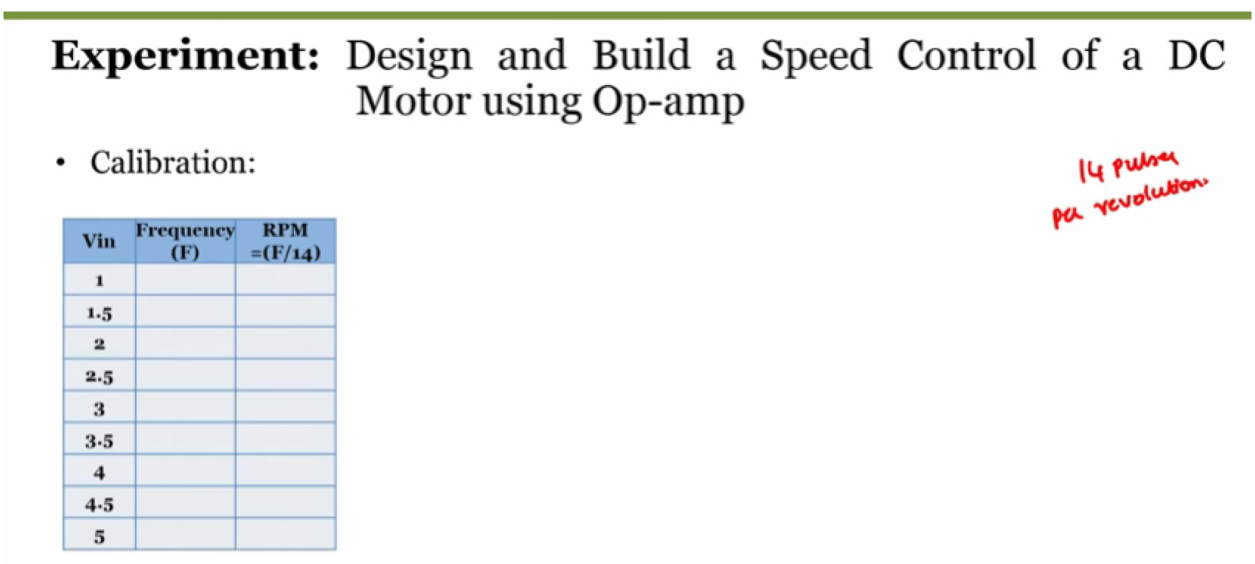

And the datasheet says that, it will give you total of 14 pulses, per one revolution.

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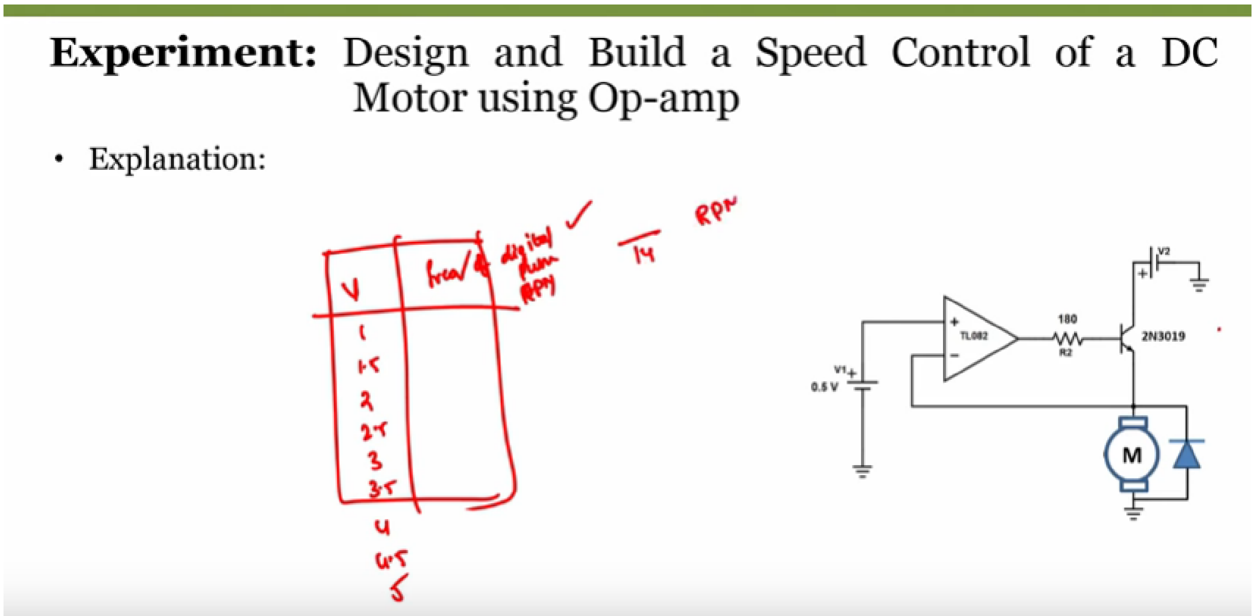

So, to understand, the working of the circuit. So, now what we have to do is that? We will, will create a table, we will give different voltages, starting from one, one point five, 2 two point five, 3 three point five, 4 four point five and five. We will observe, the frequency, frequency of digital pulses by using CRO or we can also count, how many number of pulses that we are getting which gives me the RPM. But, if you know the frequency, of the digital pulses, then dividing the number of digital pulses with 14, gives the exact RPM of our motor. Why we have to divide with 14?

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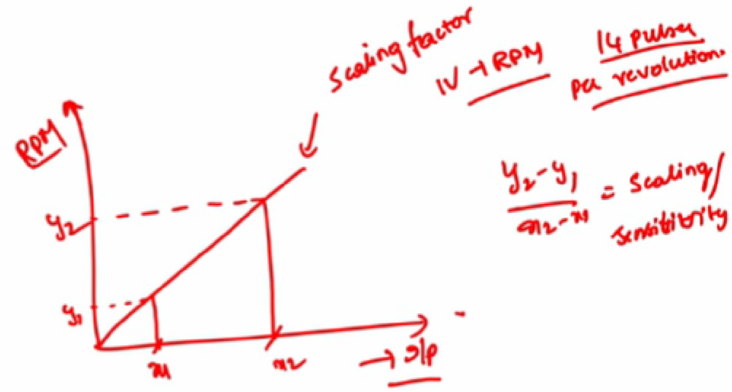
Experiment: Design and Build a Speed Control of a DC Motor using Op-amp

- Calibration:

Vin	Frequency (F)	RPM =(F/14)
1		
1.5		
2		
2.5		
3		
3.5		
4		
4.5		
5		



The reason is that, it gives a total of 14 pulses per revolution, so that's why, first we will vary, input voltage will provide a different input voltage, with the resolution of 0.5 and we will observe the frequency at which, the output encoder is giving or we can count how many number of pulses that it is giving ,then we will divide, rpm with 14 and we'll see a graph between, input voltage and the RPM. So, this gives us understanding about, the scaling factor or mapping factor. which means that, upon application of 1 volt, at what RPM, the motor is rotating, of course it should be linear, we will also verify whether it is linearly rotating or not. And what, what it's sensitive factor? So how do you calculate the sensitive factor? If you know, it so if you know, one particular voltage ,what is the frequency at rpm that we are getting. And another particular voltage say, some x1 and x2, say this is y1 and this is y2. So, by doing slope of the line, which is nothing but X 2 ,y 2 minus y 1 by X 2 minus X 1, which gives me the slope of a line, this is nothing but a scaling factor our sensitivity factor, in this case, sensitivity. So, once we understand the sensory factor, if the sensitivity factor is good enough for us, to provide it as an input set point, we'll go ahead with this or we can also change ,our own sensing, scaling factor, we can also provide our own mapping factor and we can cure, complete system to our own noting factor. But, before that we should understand, the relation between, the input voltage to the RPM, for that. Now we will do, we will demonstrate, we will show you, with varying, varying inputs, how exactly the output is going to come.