Sensors and Actuators
Department of Electronic Systems Engineering
Indian Institute of Science, Bengaluru

Lecture - 27
Demonstration of Thermal Actuators Using Comsol

Hi, welcome to the Sensors and Actuators course, today we will be discussing a pressure sensor. I will be showing a demo with the pressure sensor called BMP 180 which is developed by Bosch. And also I will be explaining the working principle of a pressure sensor. Professor Hardik must have already discussed with you, regarding how a pressure sensor is fabricated, how a diaphragm is fabricated out of silicon and other things.

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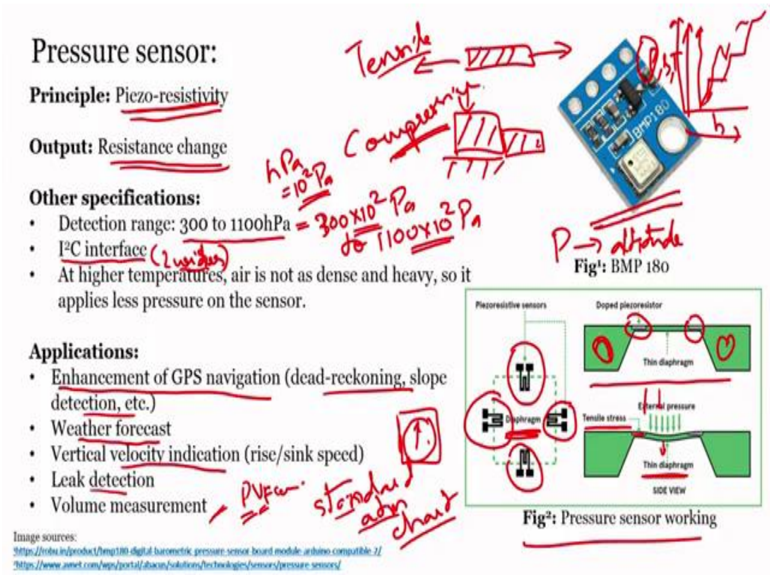

So, now I will be showing a practical example of one pressure sensor like that. Today we will be discussing this BMP 180 sensor, that you can see only this side. this is pressure sensors that we are going to discuss today.

So, BMP is like many other sensors that are working based on piezoresistivity. You must have also heard about piezoresistivity, piezoelectric nature and so on. It is basically like if it is a piezoelectric material, then if you apply the pressure it will generate a potential; while a piezoresistive material will exhibit a change in resistance. What a pressure sensor over here, we will be using is it is piezoresistive property. You can see it here. This is how the construction aspect of a pressure sensor that we are going to use here. you can see here, there are piezoresistive and in the sender, there is a diaphragm.

So, a diaphragm and in the four edges of the diaphragm, there are piezoresistives. And the diaphragm over here, this side view or a section view you can see there is a piezo resistor here, there will be a piezo resistor here on both sides, and the thin diaphragm is between it. This diaphragm is actually like hanging on these four piezoresistives. That is how the construction of it is. this will be a solid region and by micro machining operation we have got a thin diaphragm and we have also build piezoresistors on it. Now before going furthermore into this, I will like to tell you about some more things, regarding pressure.

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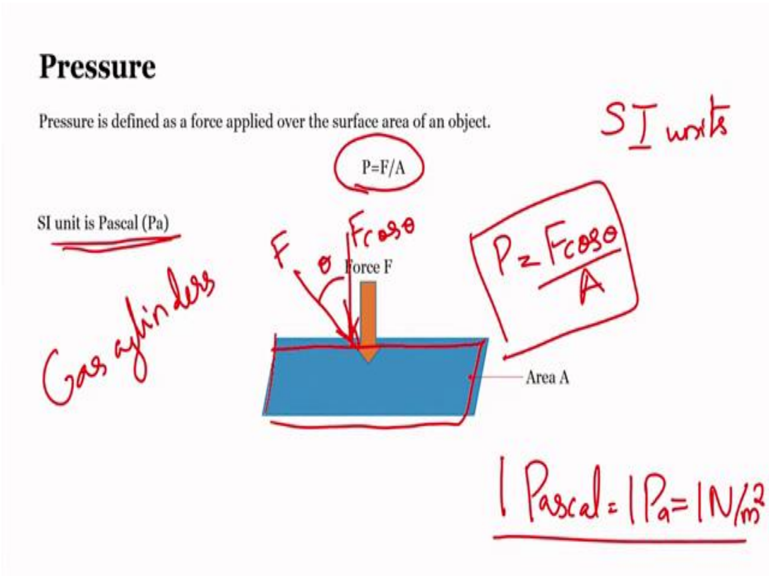

So, what is pressure actually? you must be aware of force, what is a force? Force is like; force is what you apply on an object to move it. If I am moving a cart by pushing it, I am applying a force

So, this is what force. We know different kinds of piezoresistive; gravitational force, electrostatic force, mechanical force such as many of such stuff is there. And the pressure is a concept that is related to force and it is the pressure is defined as the force applied per unit area or the pressure is the force applied over an area. And the equation of pressure P=F/A, where; F is the force applied and A is the area on which it is acting.

And the pressure is always acting normal to the surface and this area is the surface area and the force acting on it is considered as the normal force acting on it.

So, you can see it here. This force over here is a normal force and not inland force. The pressure if, it an inland force like and what I am going to show now. if it is an inland force, then the normal component will be like this over θ is this is F, then this is going to be F cos θ and then the pressure P acting on the surface will be F cos θ by area. it is the normal component of the force by the area over which it is acting.

So, in S I units you know S I units; in S I units, the unit of pressure is Pa, and 1 Pa over 1 Pa that is how we denote it in short form, =1 N/m^2. This is the unit of pressure. We told you that, when we apply a force it acts on an area and that force per unit area is called pressure and it should be normal, the force taken here is the normal force. as I have, even if we apply an inland force this is how the force is resolved and pressure is calculated.

So, you have an idea about pressure; when we, you must have heard of a gas cylinder and there will be prescribed maximum limit for the pressure that can be stored in a gas cylinder and such stuff are there. We will go into that now. there is something called as barometric pressure. What is barometric pressure? You must also hear of it as atmospheric pressure also.

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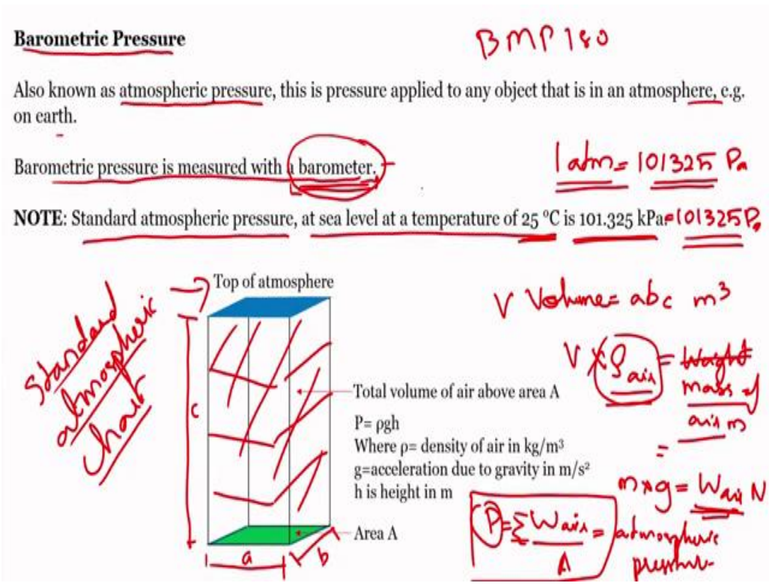

So, here I have got a diagram, here you can see this cuboid over here, it is written top of the atmosphere, over here. consider this cuboid and this is the surface of the earth, I am just giving an example; this is the surface earth and considered a cuboid like this. And inside this cuboid there will be what air; this air also has it is own density, water has a density of like 1 gram per centimetre cube, 1 gram per cc; and similarly methyl have more density than gases and so on. You must have learned these basics before also. Consider the atmosphere it has air and I have considered this area of earth and this much air is over here, inside this cuboid, this is the top of the atmosphere. whatever air is there in between the top of the atmosphere to the surface of the earth, will be causing a weight. This will have a weight.

And in this case we could calculate it as; see if the this is area a length a and this is length b and say there is a height c; then the volume of air will be a x b x c; whatever unit, maybe could be in metre or whatever it is. the volume can be a b c, say I am saying it is in metre cube though, so we have the volume. And if we multiply this volume V, this volume V x density of air; I am writing rho, rho is the density of air then what we get is what the weight of air right, or mass of air actually. It is the mass of air and if I multiplied with, so this is the mass air say m; and if I multiplied this mass with acceleration due to gravity, then I get the weight of air.

So, this much weight, weight is equivalent to force and then Newton the unit of weight is nothing, but Newton. this much volume of air over here will cause a weight of W air and this will create a force only. And this force acts on this area A the pressure acting over here P=Wair correct, W air by this area. This much force is acting here. This is a very basic concept and then, we call this pressure as atmospheric pressure. It should be understood that this is not exactly like the density of air is not a constant like I assumed here as rho air, it is not constant; it varies with the altitude you know that there are different layers heights for the atmosphere. it actually varies, so in the troposphere, it will different, stratosphere it will be different and it depends on temperature and a lot of parameters and we have something called a standard atmospheric chart.

So, this is not important for the course, but you should understand that there is something called standard atmospheric chart, which is not just a chart, it has the relation between temperature density and a lot of parameters related with atmosphere it is density a lot of things; it is actually good things to know, it is like very fascinating things you can actually look into that anytime. Even though I told this as a symbol of this, it is not like this. it does this pressure actually is not like this, it is actually a sum up of the various densities and other things.

So, at different layers we will have different densities, different weights all sum up to finally, this. we can say the total weight, sigma of what our weight of the area is the atmospheric pressure. And at sea level, it is been calculated that the standard atmospheric pressure at sea level at a temperature of 25^0 Celsius. This value is called standard atmospheric pressure and it is at 25^0 Celsius. If temperature changes pressure changes, so it is very important.

So, this is the standard atmospheric pressure. we also have given it as a term or a unit as 1 atmosphere (atm)=101.325 Pa. This is a standard value, remember this always; 1 atm=101.325 Pa. This is called one atmospheric pressure. If you are going to the nearest sea and then the pressure of air acting on you is 1 atmosphere=101.325 Pa. this is also called barometric pressure. This is called barometric pressure it is right, is also known as atmospheric pressure, this the pressure applied to any object that is in an atmosphere example on earth.

So, barometric pressure is measured using an instrument known as a barometer, this must be we all must have studied this during our small classes itself that, what is the instrument used to measure pressure, it is a barometer. This is also a sensor. we are going to see how we are you going to use the BMP 180, which we discussed earlier as a, to be used as a barometer. How a barometer is mechanical in nature, the conventional one; but this one is an electronic parameter that we are going to do. this is the one thing, why I said about barometric pressure I will tell you.

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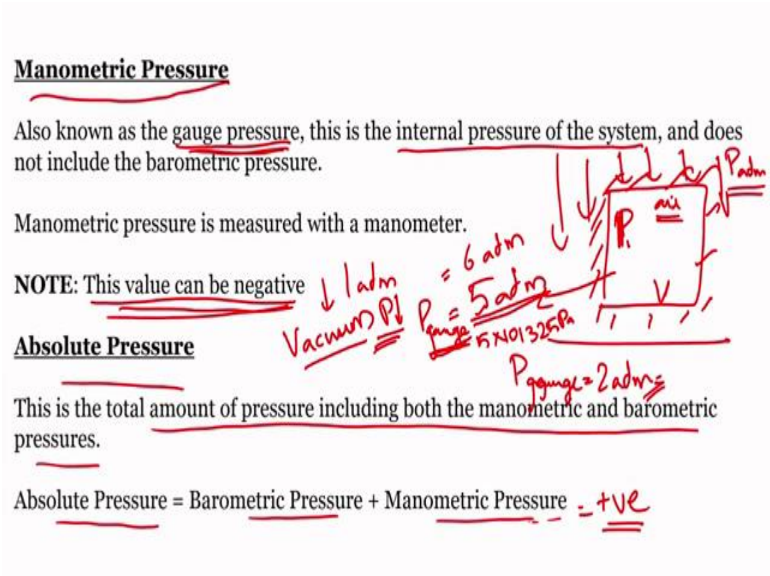

So, there is something else called manometric pressure also. we consider this, this is a cylinder this is a closed cylinder and inside it there is air is there; and the air is stored as a pressure. Air is stored as a pressure P and the volume of the container is fixed say volume V.

So, there is P and V, I am just naming it as, let it be P and see this cylinder is on the surface of the earth. there will be atmospheric pressure acting on it right, atmospheric pressure will be acting on it, correct there is a term like anyway there will be a pressure of around 1 atmosphere always on the surface of the earth, h correct. Like, so it is already like 1 atmosphere is added to any pressure measurement we do. We came up with a new term called manometric pressure, so that we can get a value that starts from 0. It is nothing, but it is the only pressure that is build up inside the system. it is also known as gauge pressure, it is known as gauge pressure; manometric pressure is also known as gauge pressure.

This is the internal pressure of the system and does not include barometric pressure. it is like a cylinder, this cylinder has pressure inside is equal to 5 atm; 5 atmosphere is nothing but 5 x 1 atmosphere or 5x101.325 Pa; that much pressure that like higher pressure, 5 times their atmosphere is inside this. Then the gauge pressure=5 atm, P gauge is or P manometric=5 atm; but the real pressure or the absolute pressure that we will discuss now is equal to 6 atm. Because this 5 atmospheric pressure or the gauge pressure is devoid of the atmospheric pressure or the barometric pressure.

So, this is like a new reference that is devoid of the external pressure; anyway, we know that there is an external pressure equivalent to P atmosphere. We will say that, why we have to say again. Keeping the atmospheric pressure as the reference point, we will count from that. 2 gauge pressures of 2, P gauge of 2 atmosphere means nothing, but 1 atmospheric 2 atmospheric pressure greater than the normal atmospheric pressure that is it. That is what a gauge pressure or manometer pressure is. very important to note that this value can be negative; this value can be negative; because we see the atmospheric pressure that we discussed does 1 atmosphere. We know that when we create a vacuum pressure decreases, correct.

So, the pressure of the inside the cylinder, if we create a vacuum will decrease beyond 1 atmosphere, correct. Since 1 atmosphere was considered as the 0 for a gauge pressure calculation, this value becomes negative, now this p gauge will be negative. the manometric pressure can be negative; while the atmospheric pressure cannot be negative. And then we have the absolute pressure. It is nothing, but the total amount of pressure including both manometric and barometric pressure. there is absolute pressure, which is equivalent to the sum of barometric and manometric pressure and which will always be positive.

Because manometric pressure can reduce up to say, if we create a lot of vacuum, excellent vacuum then will be like be negative; but it does not go below barometric pressure a lot. The absolute pressure will always be positive. this is the concept that you need to know before we go into details of a pressure sensor. And one more thing that I think you should know is some basics of thermodynamics that we must have known before.

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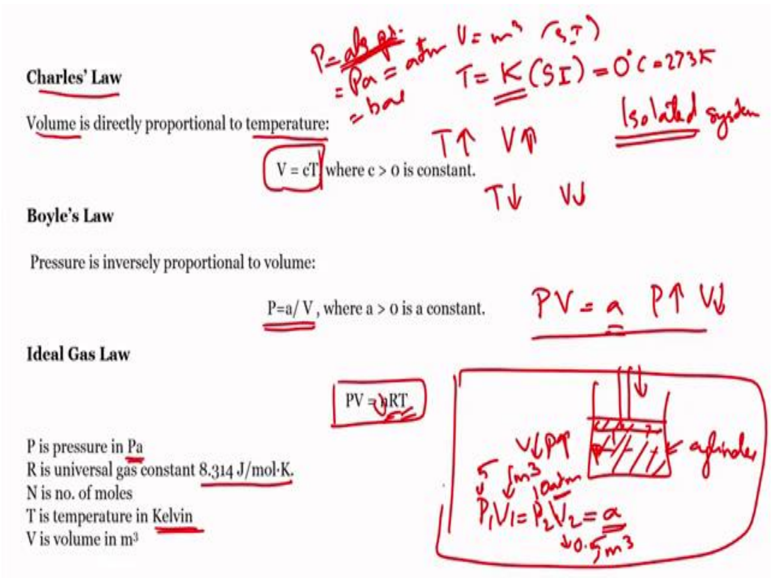

So, this is the, it is the Charles law actually. Charles law is nothing, but volume is directly proportional to the temperature, the volume is directly proportional to the temperature. when the temperature increases volume also increases, when the temperature increases volume increases or temperature decreases, volume decreases.

This case is very tricky actually; this is in case of an isolated system actually. The isolated system means, in no energy is lost and no energy or matter is lost outside; then if we increase the temperature volume will increase for an isolated system. Then when we increase the temperature volume will also increase, when we decrease the temperature volume will decrease. And then there is, Boyle's Law that says that pressure P is inversely proportional to the volume or PV is a constant. if pressure increases volume decreases.

One simple example is, consider this is a cylinder, then keeping a piston-like in the SI engine and all. if I apply here what happens is, the pressure inside the air is inside this cylinder, when I apply the pressure here, the cylinder is the piston is going to come down and the volume decreases correct, volume decreases. When volume decreases what happens, pressure increases; you know this example, this example we will be showing you today, that is why I am just telling you this basic example, so that you will have the idea. And one more important thing that you have to remember is when we use these equations, we should remember that volume can be in metre cube or any other SI unit does not matter; but the temperature should be in Kelvin, Kelvin is the SI unit of everything should be in a standard unit.

Kelvin is the SI unit of temperature, so you know that yeah 0^0 Celsius equal to 273 Kelvin. the temperature should be in Kelvin and pressure should be in some standard unit and this standard unit should be in absolute pressure. We can use Pa or atmosphere or bar these are all units of pressure only; but we should use the absolute pressure, not the gauge pressure, the absolute pressure in the calculation. For example, I would say, according to this relation PV say constant, we can say that P1 V 1 equal to P2 V 2, right; you understand that right, yeah.

So, initial pressure and the initial volume the product of those two will be equal to P2V2 will be is equal to a constant a correct; that is what according to Boyle's Law happens. initially, if the atmospheric pressure was 5 atmosphere and volume was 1 meter cube, then if I increase the pressure to say 10 atmospheric absolute pressure; then the volume will decrease actually to how much to 0.5 so that this constant will remain same. this is how Boyle's Law works.

And then we also need not mention much, but ideal gas law is there that is PV=nRT; where N is the number of moles, R is the universal gas constant which =8.314 Joule/ (mole Kelvin), and T is the temperature in Kelvin. Remember always use the SI unit and the SI units of pressure should also be in absolute pressure, very important thing always remember this.

Now, we will be going back to the pressure sensor. this is the BMP pressure sensor that we are going to demonstrate. Now I am going to apply some force here, external pressure will be acting over here. what happens is, due to this external pressure that is going to act here like this, what happens is tensile stress is going to be produced. Stress is of two types, not two types more than two types are there; but I could simply say that you could pressure can be tensile, stress can be tensile.

Stress and pressure are almost the same, but you know, we are not mentioning that you will be confused. there is something is known as tensile stress, for example, tensile stress is the stress developed when you pull a block from this side and this side. it will stretch just like a rubber band you stretch, so that is the tensile force. And you take a sponge you keep it somewhere and you apply force, then it compressor right and it reduces the size; this is called as a compressive force. And the stress is called compressive stress or compression stress, tensile stress, compression that is the stress that is going to happen.

The here tensile stress will be produced due to this external pressure over here, on the thin diaphragm. the thin diaphragm will deform and when it deforms or it comes down what happens is, this since this piezoresistor does not stretch much, there will be tensile stress. And this will goes the change in resistance and that is why we are saying that this is a piezoresistive sensor.

So, the output is actually a resistance change. There are four piezoresistors here and we will be using an. we will be using a signal conditioning unit to get this output. this is how a pressure sensor works. And this BMP 180 has a detection range of 300 to 1100 hector Pa, =300 x 10^2 Pa, (hector Pa=10^2 Pa). 300x10^2 Pa to 1100x10^2 Pa, is the measurement range of this pressure sensor.

So, and it uses something else called as I square C interface with Arduino when I am going to show the example I will tell you. This is a different mode of communication, this is also a serial mode of communication only; but it uses 2 wires, for the 2 wires for communication. It is like a serial communication only; but with very high speed, so it is an I square C communication, we would not be going too much into it; and yeah, so this is the main thing, cool.

Then why we use this is, I told you initially about the standard atmospheric chart rate. We talked about the standard atmospheric chart there, the pressure variation as well as density variation everything will be plotted, it is like a graph like this, various values will be shown. It is like; I will be plotting pressure here, density here, and the temperature here on the y-axis in different y-axis; it will be plotting altitude h on this thing. And it will be like the temperature there, the first increases then drop, it stays similar like this and the pressure actually increases, then Strokes something like this, it is not exactly like this, but something like this.

Why we develop this standard atmospheric chart is, mainly because we need to do a fly aircraft, send rockets and everything. Since all these things fly in the air, we need to exactly know the pressure variation, so that we could adjust the thrust and everything in the aircraft. these pressure sensors are widely used in aircraft and other things, to measure the pressure outside and do the calculation as well as. And based on this since the atmospheric pressure at that height will be more or less they constant, they even use a pressure sensor to calculate the altitude. They will measure pressure and predict the altitude. A lot of applications are there for pressure sensors; why it is written as enhancement of GPS navigation is that when we get the pressure value we will be exactly able to know the height range and all.

So, slope detection everything, then we can do weather forecast when temperature changes there will be a change in pressure, so we can use it for a weather forecast. And vertical velocity indication, so this is for the aircraft they have instruments an inside it. It is something all like this with a, it is called a vertical velocity indicator and all. What happens is, when it moves fast when moves fast based on the pressure variation it will show the velocity at which it is moving up and down. And leak detection, if we keep a process sensor inside a cylinder, if it is leaking the pressure will drop gradually and we will be able to know that there is a leak. And for volume measurement, as I said PV is a constant if the pressure decreases we know that the volume of air also if the pressure decreases then the volume actually increases.

So, we can do a lot of things like this. this is about the pressure sensor. Now we will switch to showing how it happens in Arduino.

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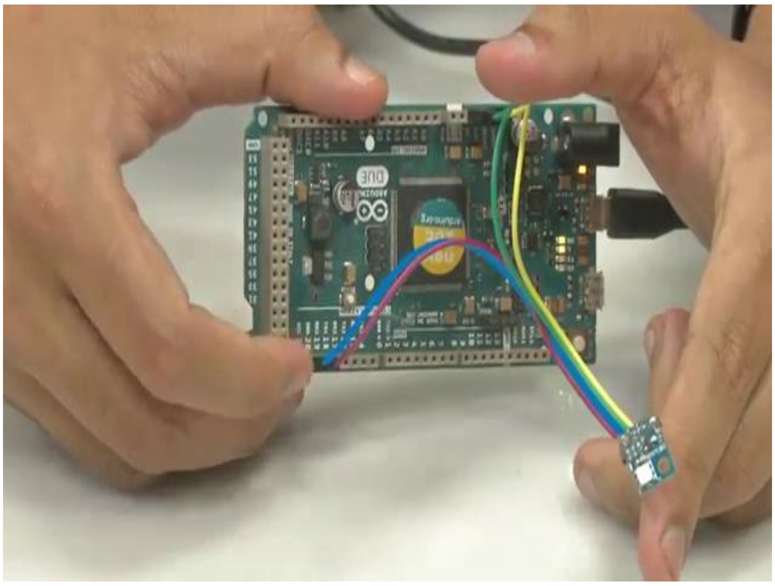

So, you can see here, I have connected the BMP pressure sensor to the Arduino due. We can see here and there are four cables that are coming from the BMP pressure sensor; it is the same that represents is almost the same thing that I showed you in the presentation. you have here, the casing with the thin diaphragm inside and four cables come out of these, out of which one is 5 volt, one is ground and there are SDA and SCL. These are the two connections that we use for I square C communication, you can see here I have already connected it. Now, we will move on to Arduino programming.

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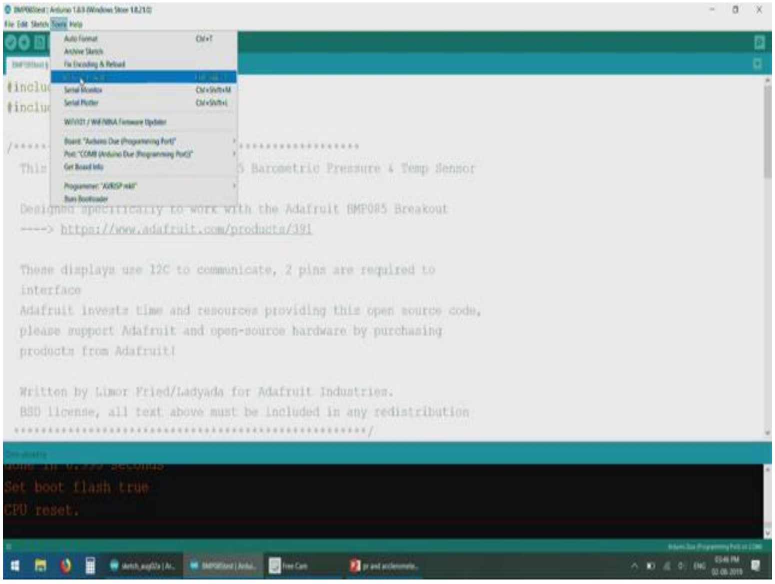

So, here it is the same thing we always used to do, we can see that in the tools I have added a new library, BMP 180.

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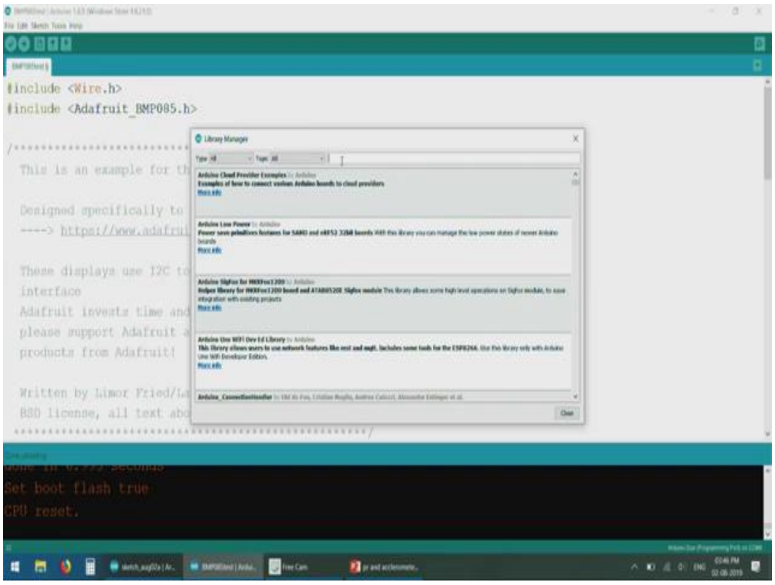

I click manage libraries, inside which you can search BMP 180.

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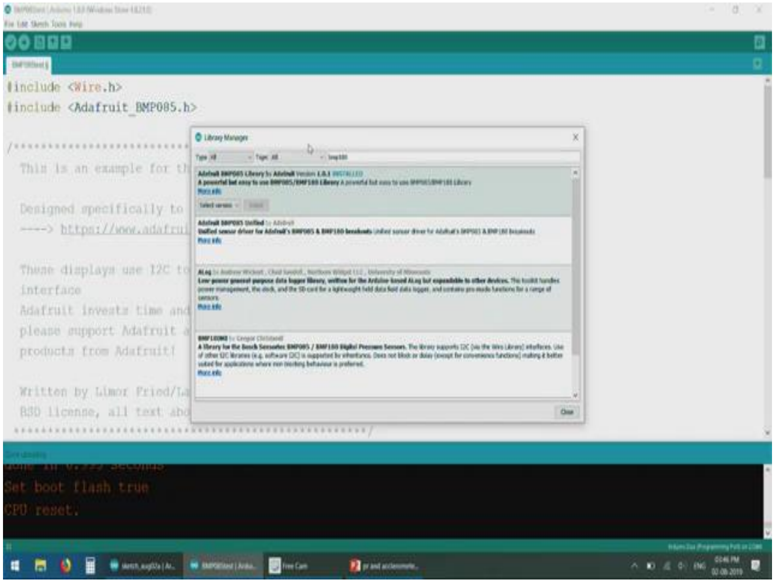

So, you can add it; otherwise, it is a bit of tricky to code the I square C communication by yourself; but it is better to use it directly, if you are not very experienced. I have already installed it, BMP 085 or BMP 180 library is available here. you can just install it, I have already installed it.

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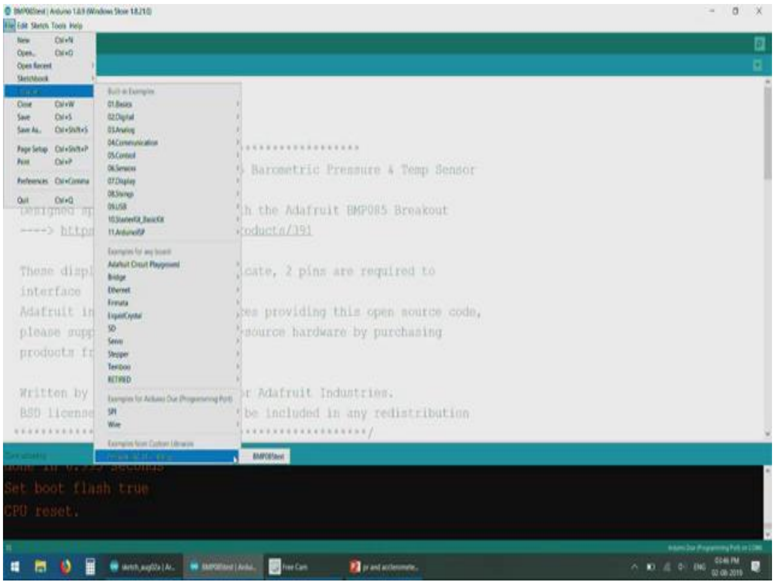

Now, we can see that from the file examples, I have selected this code, Ad fruit BMP library, here this is a code over here.

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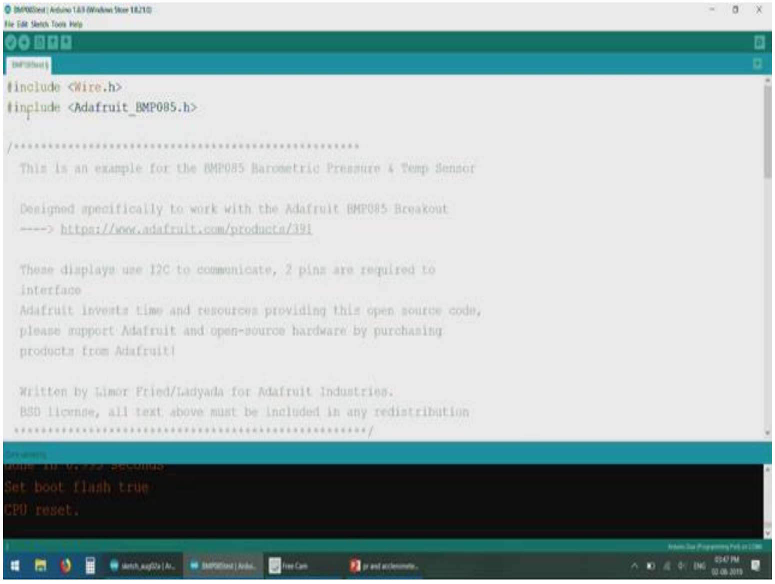

And there is a header that we have to call, for Wire.h that is used for the I square C communication. Wire.h is popularly used for communication protocols and it has a lot of function inside it and we also added the Adafruit BMP 085 library into it,

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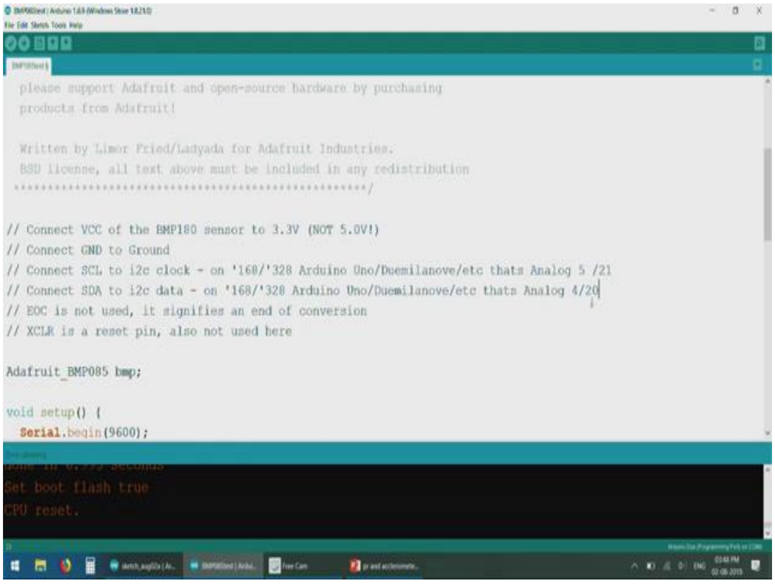

Then we already since we have connected the VCC of the BMP 180 sensor, here it is 085; but in our case, it is 180, it does not matter anyway, it is a command. And it should work at 3.3 volts, it is working level is 3.3 volt and not 5 volts. You should remember that, connect the ground to the ground of the Arduino. And the SCL pin from the SCL of the clock pins from the sensor to the clock on the Arduino. And in case, since we have to use the Arduino due, the SCL pin is pin number 21, digital 21 and the other pin is pin number 20 SDA pin is due is pin number 20. we have connected like this.

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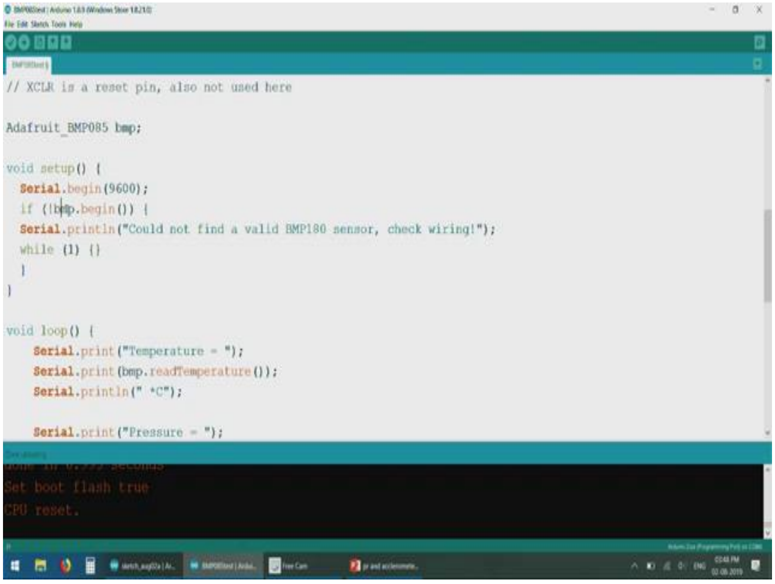

Then there is a bit of code over here. it is bmp.begin, it is like the communication we have used before also the Serial.begin. Similarly, we have used bmp.begin here; that means, serial communication is starting between the BMP sensor and the Arduino board. Then inside the void loop, we are using a set of functions like bmp.read Temperature and other things and we have to print it on the serial monitor. Why we are doing this is the, we can easily use the sensor without much coding so that you can easily understand. what will be show is, Temperature; there will be Temperature feedback from the pressure sensor.

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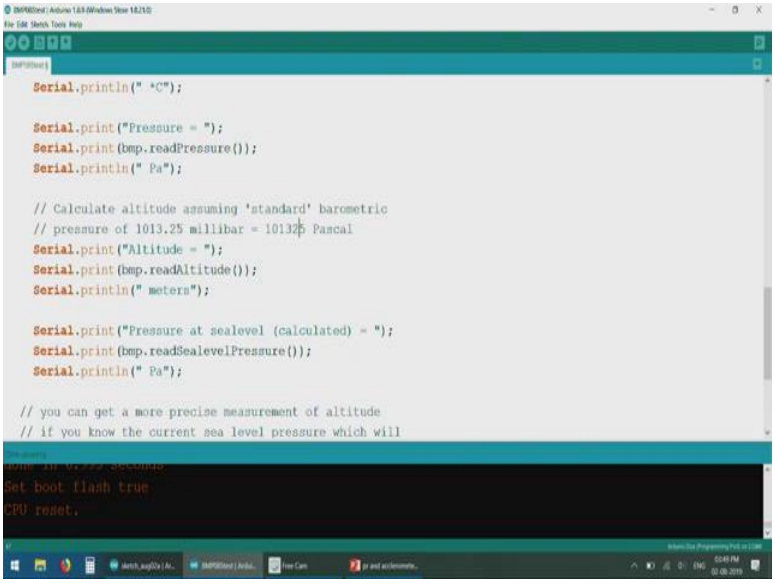

So, this pressure sensor also has, temperature measurement inside it. we can read the temperature, then also we can read the pressure and based on the assumption that standard barometric pressure is 1013.25 millibar or 101325 Pa, we can calculate Altitude,

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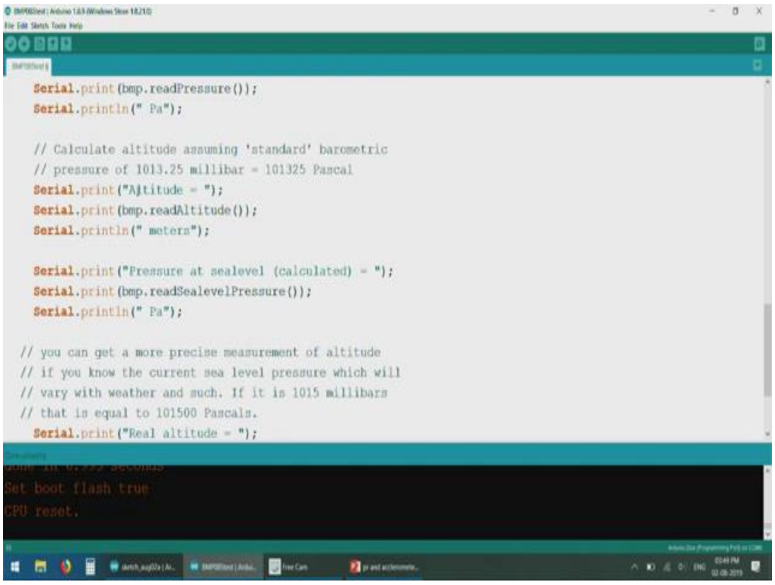

As I already said aircraft use this method to of like the measurement of pressure will be converted to the measurement of Altitude.

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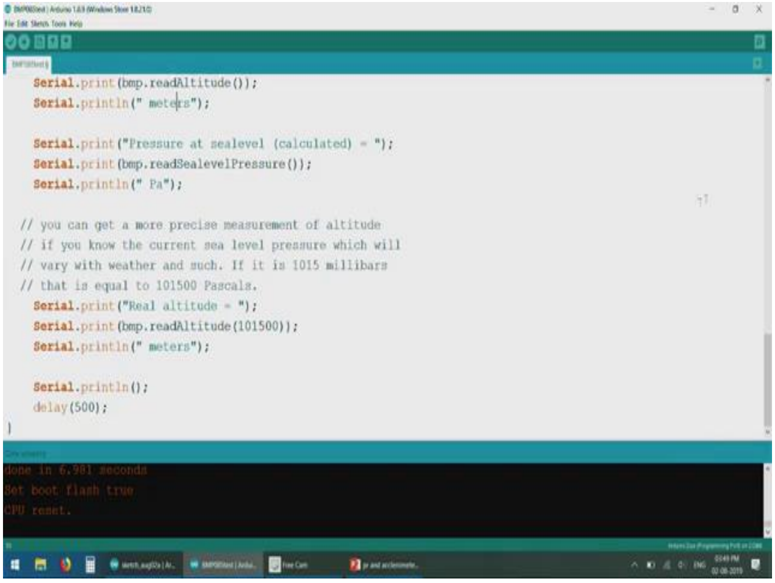

So, you can see that altitude can be measured, the pressure at sea level can be measured and a lot of things are possible, the Real attitude everything.

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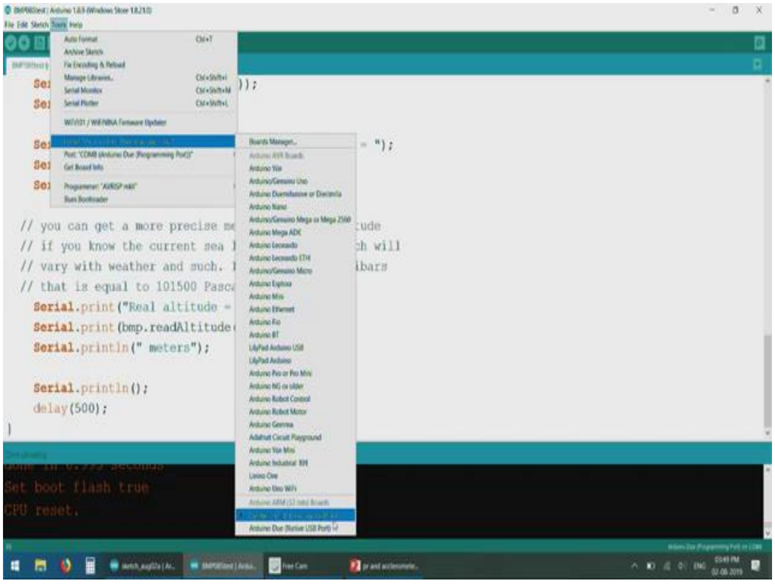

So, I am just going to select the board as Arduino Due even programming code, it is already selected and the COMB Port and I am going to verifying the code now, and I am uploading the sketch now. this code will be uploaded into the pressure sensor now. Now, if I select the serial monitor, after uploading here the blue progress bar SCL, it is done uploading.

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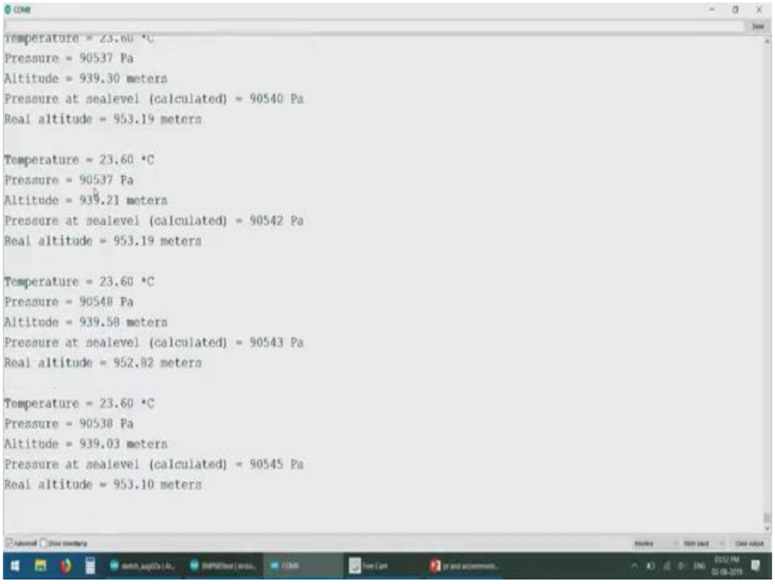

Now, I am selecting this, see I can see the temperature and other things. It is showing the temperature as 23.5^0 C , and the pressure as 90 54; 90539 Pa, and then altitude of 939 meters. I am sitting in Bangalore right now Bangalore is at an elevation of around us, according to the sensory it traces at 939 meters, you can actually check how high is Bangalore from the sea level to cross verify it, I do not know exactly, yeah let see.

And also we can see that the pressure is this pressure is the absolute pressure right and this absolute pressure is less than the atmospheric pressure; it is because at higher altitude this pressure actually decreases the atmospheric pressure decreases. it is below 101325 Pa. And if we measure the gauge pressure using a gauge pressure sensor over here, then what happens is, we will get a negative gauge pressure right; because the gauge pressure = (absolute pressure-atmospheric pressure or barometric pressure). So this is equal to 90538 Pa-101325, which will give you a negative gauge value.

So, this is how we connected between absolute pressure and gauge pressure. You should understand that; and similarly, you must also remember the Charles equation, Boyle's equation, and everything.

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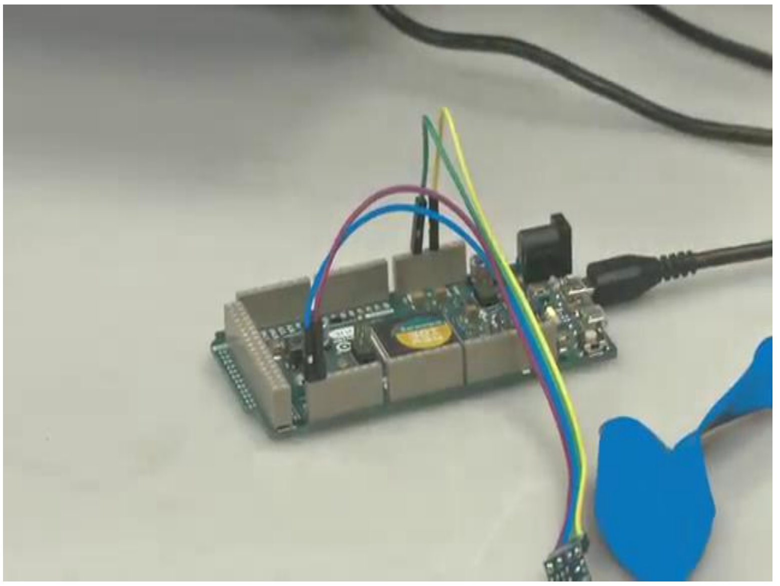

Now that you have seen this, I will show you the variation in the pressure also. I will put the gas sensor inside a balloon. Inside this balloon over here. And I will inflate the balloon and seal it. when I do that, what happens is, the volume of the air within the balloon will be like concentrate; because once I seal it off the air cannot go out, correct. if I compress the balloon what happens is, the pressure will build up according to which equation; the equation over here that we have seen which one is that, see, it is Boyle’s law. According to Boyle’s law what happens is, when we decrease the volume pressure will increase.

So, according to Boyle’s law what happens is, if we compress the balloon the pressure will go up and we will see that on the serial monitor. Now, we will do that once.

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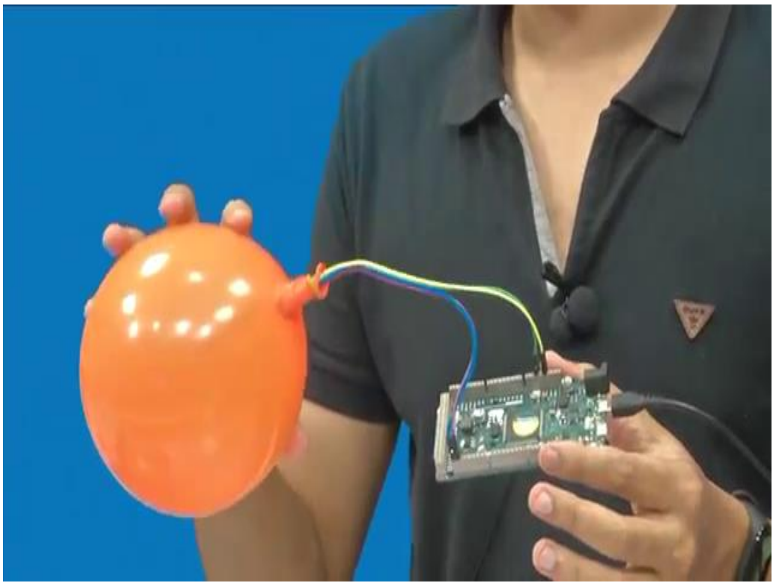

So, I have put the pressure sensor inside the balloon. It is like this now, you can see that pressure sensor is within this and I have connected everything. Theoretically what should happen is, when I compress this, the volume decreases and the pressure should increase; but since this is a balloon it can deform, it can deform. the pressure in change would not be so visible; but still, you can see a pressure change in the serial monitor.

Now, you just look at the serial monitor now. The value of pressure is around 92000 Pa 92600 or 680 Pa. If I am going to compress it now, compress the (Refer Slide Time: 36:31) see I am going to compress the balloon and you can see that the pressure has increased 93347. there is an increase in pressure of around 500 Pa, correct. I am leaving the hand now, again back to normal; see the pressure has even drag back to the normal 92600.

Again I am compassing it, see the pressure has increased, correct. You can see that it is calculating the pressure accordingly; but you can see what something else is, that when I increase the pressure, you can see the values that, the altitude has what decreased. It is the calculation actually an error, because when the pressure increases accordingly the altitude should also decrease, correct yeah. this is how the BMP 180 pressure sensor works. I hope you understood how the BMP 180 pressure sensor works and I think the concept is clear. You can also know how microfabricated sensors using thin, as well as thick filling sensors, are widely used. that is it.

Thank you.