Principles of Mechanical Measurements

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Lecture No. # 18

Now we go to the next chapter force measurement. Until now we have seen displacement, velocity and acceleration all the three put together is called motion measurement. So now it is a new chapter on force measurement.

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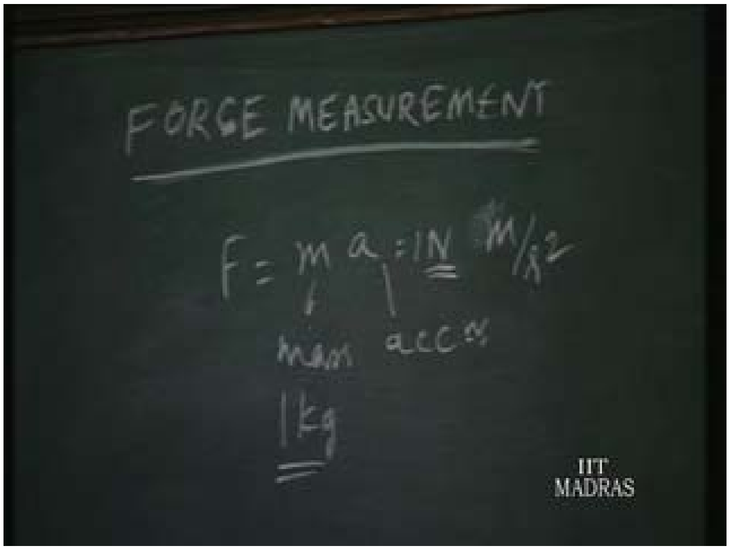

What is force? Force equal to m into a where m is the mass and a is the acceleration. So that is by Newton's law of motion, force is given by mass into acceleration. So if you want to have unit for mass then you analyze whatever units it is made up of. It is made up of mass which we have not yet seen the unit for mass whereas acceleration, we know acceleration made up of length that is meter per Second Square. So we know the standard for the standard unit for meter and we also know this unit for the second. So now we have to see what is the unit for mass under accepted by all countries that is 1 kilogram which is the unit for mass.

What is that one kilogram? It is some randomly selected body say platinum iridium cylinder kept in a Paris such that amount of mass is assumed. They might have selected some other mass also but once it is accepted that is one kilogram, now it is always referred there as one kilogram mass. So one kilogram mass is nothing but the unit, it's a mass of the unit or the product cylinder which is kept there near Paris that mass is always taken as one kilogram. So now it is made up of all the three units mass, length and time. All the three units made up of the force. Now the SI unit for force is one Newton. What is Newton? Newton is the force required to accelerate a mass of one kilogram through an acceleration of one meter per square.

So one Newton is equal to one kilogram mass through one meter per second square acceleration. When it accelerates then that force is called one Newton or one Newton force will accelerate a mass of one kilogram through an acceleration of one meter per Second Square that is our unit Newton but for calibration purposes we have got the weight. What is weight? Weight is the force of attraction of a mass by the earth, that earth attraction is called a weight on any mass. So that is g, mass multiplied by g, instead of acceleration here we have got g, g is what we have taken the nominal value is 9.81 meter per second square. That is the g value but it is a variable one at different places in the earth this value g varies but all countries have agreed to use this average value for all computation purposes.

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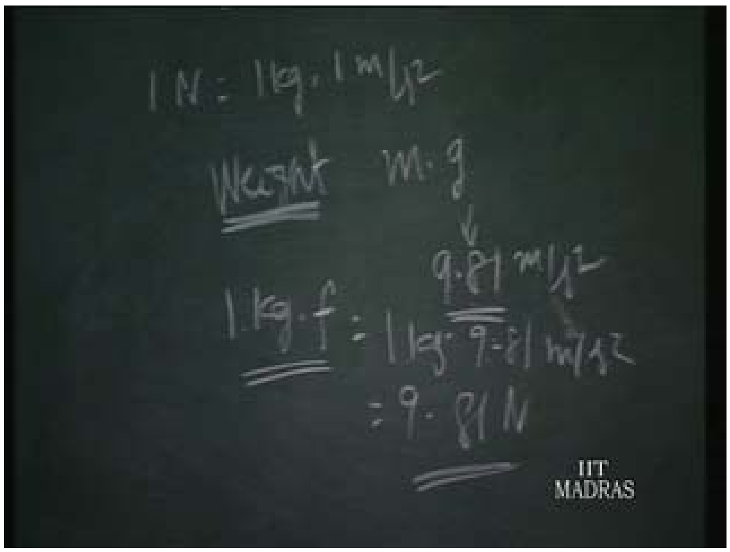

So whenever there is a mass on the earth, it is always acted upon by g so we always realize a weight. So weight was there, for example this chock piece mass cannot be separated from its weight because it is acted on by the weight always, mass to separate it from weight it is not possible. Then you have to take it into space where there is no earth attraction then you have the mass there. Since we have the weight here and this nominal value also is there, the weight is used. The unit for weight is one kilogram force or one kilogram weight that is the unit for the calibration purposes. By having the one kilogram weight we can calibrate. What is it in terms of Newton? This is equal to one kilogram force that is one kilogram mass into 9.81 meter per Second Square. That is now one kilogram through one meter per Second Square is one Newton, so here 9.81 so one kilogram force equal to 9.81 Newton. That is the relation between one kilogram force and the Newton.

So now people under different places they can go for the one kilogram weight itself as standard for the force, so going for Newton because kilogram force and Newton can be related by this relation. So kilogram weight is taken as the standard for calibration purposes because one Newton to realize it, you should create a force that is some force is available already in nature. That is force due to attraction of earth so that is what we use it for all calibration purposes. Now under this topic force measurement we are going to see how the force or weight or different objects are weighed.

So far we have given importance to the conversion from the mechanical quantity into electrical quantity immediately but under this one we have got some mechanical devices, very often used or it is still used. Suppose a mechanical engineer is asked to make one such mechanical device, he should know what are the different types and principles behind it. Hence we are not going immediately to conversion of force into a voltage signal, before we do it we would like to see few of the mechanical devices. All the mechanical devices now we have got can be brought under the title lever balances.

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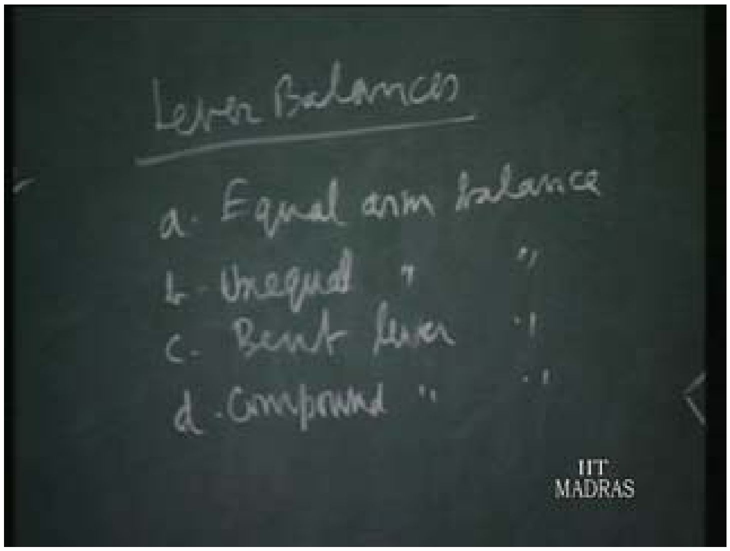

Under lever balances we have got many devices and they can be grouped under 4 category equal arm balance and b, unequal arm balance and bent lever balance and then compound lever balance. These are the 4 main types of the mechanical devices. You will see briefly what are the constructions. The common balance still used in grocery shops, very old one. Whatever the accuracy that is available in this common balance is more than sufficient.

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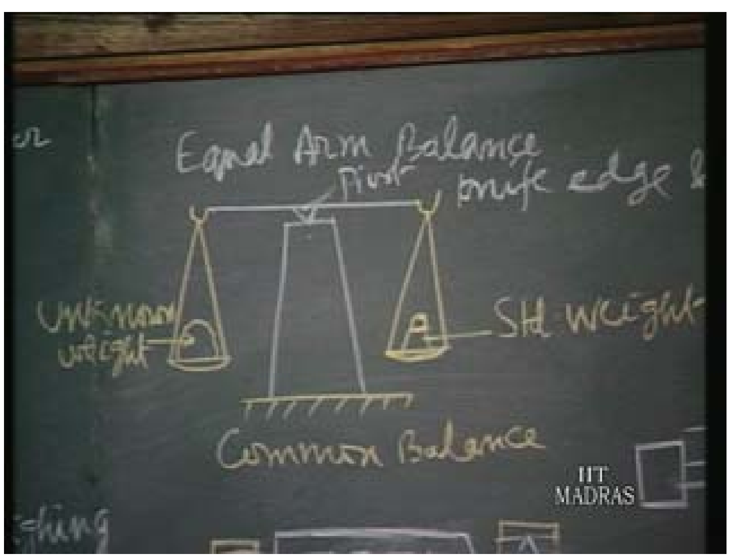

So we can weigh things of say plus or minus 10 or 20 grams, when we measure few kilogram of weight we can have the plus or minus 10 or 20 grams weight error that is acceptable and in such one you will find, only at the middle of the lever. This is the lever, equal arm balance. This is the pivot; pivot is made up of knife edge bearing. It is one of the precision bearings available and very cheap also. This is made up of some hardened steel and the pan or the support is little bit harder. Support should be sometime synthetic crystals or something like that synthetic diamond are made use of or more hardened metal is taken, otherwise the knife will flow into this support. To avoid it the pan or the support is harder than the knife. So the knife diameter is of the order of 10 microns radius that is knife edge is not a sharp end but it is always rounded, the knife end is always rounded to the radius of 10 microns.

So you find the friction radius is 10 microns or is equal to 0.01 millimeter. Hence you will find the friction torque in such knife is very small hence we got such accuracies. So here we have only one knife edge bearing and the two ends equal, this is l_1 this is also l_1 from the pivot. That is why it is called equal arm and from two hooks the pan will be hung and standard weight is put on one side. We all see whenever we go to shop and our commodity is put on the other one, until the pointer comes to stationary mark, until the mark comes and stands here we have to add the commodity and when it is there. Otherwise it will be tilting, until it comes to the standard mark we add weight and then we measure it like that. So that is accuracy say few 10 of grams may be the accuracy whereas we have got analytical balance.

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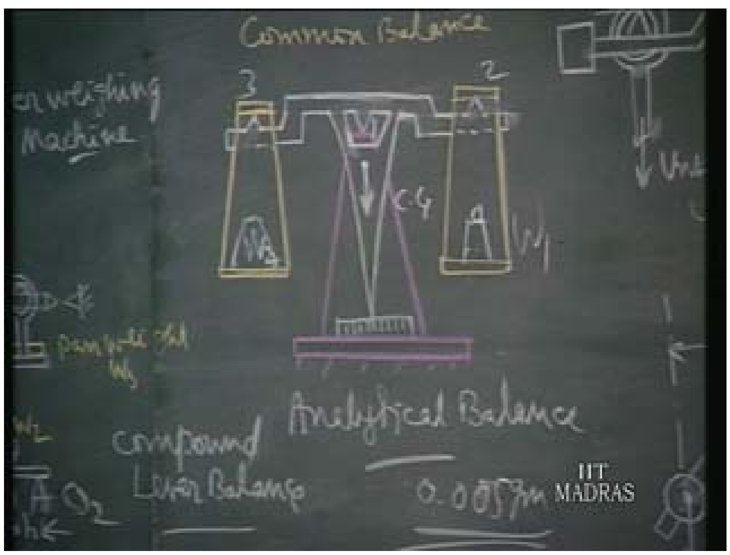

People call it chemical balance or the physical balance and where the accuracy can be of the order of 0.05 gram up to that it is possible, 0.005 gram it is possible, up to that 5 milligram it is possible. We have got standard weight boxes and we have 3 knife edge bearings, at the middle one and at end 2, 3 knife edge bearings are there, two pans from this point it is equal distance the other two knife edges and cg of this lever below the middle knife edge. Hence you find any little difference, this is the commodity, any small difference this will be oscillating in a scale, the reference point will be marked. The pointer will be oscillating. By taking for 3 oscillations readings the correct measurement can be this is w_1 known, this is w_2 unknown weight can easily be found out by making 3 oscillations.

This we have learnt in physics that is analytical balance. To maintain the precision, sometimes the manipulators are used to load this pan or to put the weight because if we stand near like this, this one may be expanded by the body of the heat whereas the other arm may be shorter. So in order to avoid this body heat, people stand at a distance and use manipulators to put the weight or put the standard weight and so on. Such operations are also available with analytical balance. A very precise measurements are made and more precise measurement can be made by calculating the different volumes it occupy and buoyancy force of air acting on this bodies of standard weight as well as this because standard weight will be normally occupying smaller volume and commodity may occupy larger volume. So here buoyancy force will be more than this. That can be accounted and the precision of one part in 10 to the power of 8 also can be found out by this analytical balance methods.

So for precision measurement we can go for it but nowadays we have got electronic balance which gives up to 0.001, that is 0.1milligram accuracy, you have got in electronic balances. So they were used but in some places there may be found this is analytical balances. Next one is unequal arm balance, here one is drawn.

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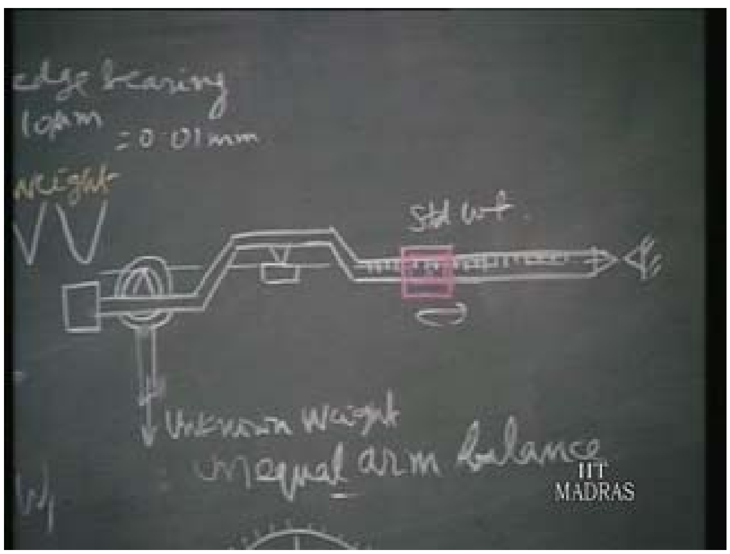

Now the advantage is with a smaller weight, this is standard weight. By having a smaller weight we can measure the higher unknown weight that is advantage of this standard weight that is moved over a scale at a longer lever arm than the loading point. This is loading point where unknown load is connected. So by having small weight we can measure a larger weight but before that we should see one more thing, even though we compare the mass here but in essence we are comparing two moments. The moment we put a mass immediately g come into picture attraction due to earth and it becomes a weight so weight w_1. When weight w_1 acts at a distance from a pivot, it is w_1 into l_1. So w into l_1 is the movement of this mass about this pivot. Similarly when add weight, this weight w_2 is obtained until w_2 into l_1 is equal to w_1 into l_1. So in essence the process of measuring weight is the process of comparing two moments. Even though mass we are measuring but actually the instrument measures to moments, until the two moments come equal we are adding the weight that is when they are equal we find the pointer stands vertical.

So in all measurements we are comparing only moment here, more or less moment because mass cannot be separated from the force and force acts from a distance, it is a moment. Here because longer arm, the movement with a smaller weight we get this larger moment and here larger load with a smaller moment and we can equalize until this is moved to and fro, until the end tip of lever stands against the reference mark, after adding the weight here. Then we make a reading about what is the weight and that is how it is made. One advantage is here in the equal arm balance, the unknown weight and the standard weight should be equal. So we should have standard weight until we could reach the range full range but here by having a smaller weight we can have the larger weight we can compare.

The problem here is we have to move this and then find the weight, so sometimes we may not be able to or we may not like to do that motion. When the moment we put the load we want to have the reading, such a thing is there in the bent lever balance. This is a bent lever balance that is third type bent lever balance. Say this is the lever bent in this form and at the one end we have got this knife edge and the pan. The other end we have got fixed weight w_1 acting at a distance b from the pivot, from the knife edge. This is the knife edge supported and above knife edge we have got, as part of the lever a pointer is attached.

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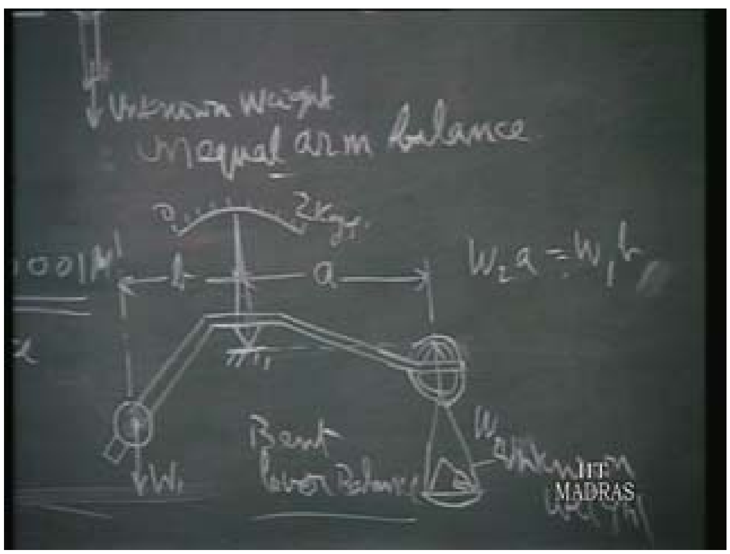

So the moment we put the unknown weight here then unknown weight if you call w_2, w_2 into a is the moment because essentially all these lever principles we are comparing moments w_2 and a. So it will deform until the distance b is such that w_1 into b_1. That is w_2 into a will be equal to w_1 into b_1. So the distance b, now as it tilts this b is increasing, it will increase until this relation is realized. At that time wherever the pointer stands, so this may be zero and this may be say 200 or say 2 kilogram whatever it is 2 kilogram force until then. Even though we call 2 kilogram or 2 kilogram force it represents force only, 2 kilogram means 2 kilogram force. So the moment we put the unknown immediately it deflects and we find the reading. A modified version of this bent lever is letter weighing machine. Still in some of the post offices this letter weighing machine is used this actually is your bent lever, up to here it is bent lever.

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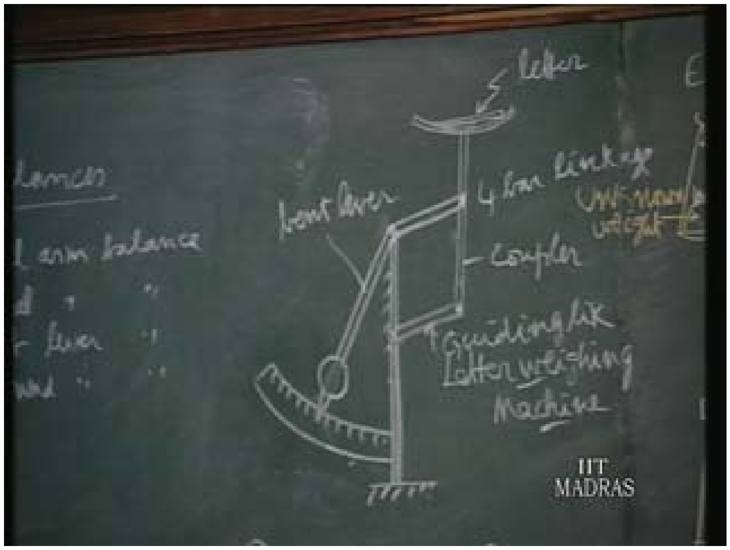

So loading is done by having another linkage, so this is the coupler and that is called input link, they are called as guiding link that actually you find here you have got 4 pin joints, so within this we have got a four bar linkage mechanism. We realize within these four linkages, this is a frame which is fixed to the ground, it is a fixed link whereas we can call it as one of them, this is the input link this is the coupler, this you can call it output link. You find input link and output link when they are equal, you find the coupler always makes motion parallel to the fixed link. That is what is happening here. When you put letters here, it moves up and down vertically, vertical motion only will be there but during its motion it may shift towards or away from the fixed link and always it is parallel.

That is what is made use of here as a coupler. From coupler that property is made is also when you put letter it doesn't tilt, it always moving vertically up and down that is the advantage. So when you put weight here it acts at the end of the bent lever, so bent lever tilts and at the other end we have got the weight w_1 and as where it stands that itself is a pointer and it moves over the scale. So from zero probably it is 200 gram up to that we can measure in this letter weighting machines.

The last type is compound lever balance that is what it is written here, compound lever balance. One of the designs is shown here in the diagram. It is mainly made up of a long lever. It is also called platform scale for compound lever mechanism. It is normally used for very large weight say for example in lorry weighing machines, lorry loaded with some commodities, if the police want to measure the lorry weight they will ask the lorry to be stopped over this platform. That is why it is called platform scale and then they will read the weight of the lorry whether it is permitted weight or overloaded that they will decide. The main advantage of this platform scale is you can put this weight w in this platform; actually this is your platform. You can put this weight anywhere in this platform; the reading will not be affected that is the advantage of this platform scale. Anywhere you can put here or there but the measurement will not be affected by the position of the weight. That is advantage we are proving that now, how the position of w doesn't affect the measurement.

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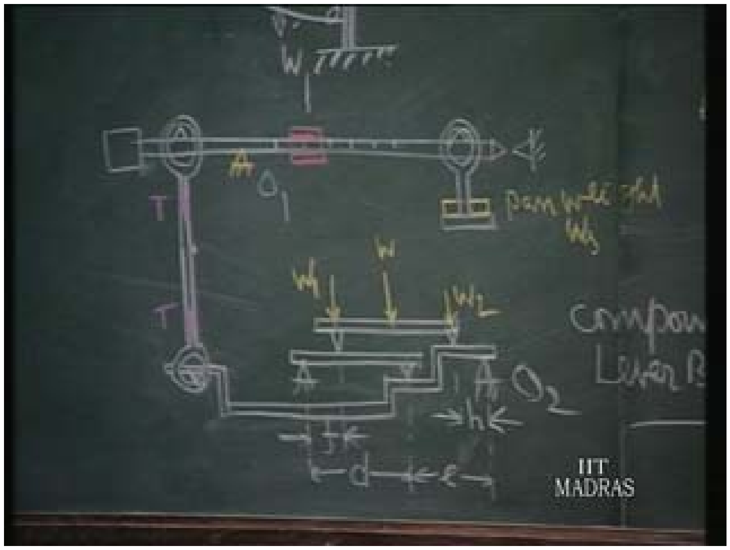

For that this is the say here you have a platform that is mounted on another platform here, one is on the lever, this lever pivoted at O_2. This main lever pivoted at O_1 and the lever edges are like this a and b, this is b lever edge and this is a. Up to the middle it is a, that is the knife edge there. So if you are taking movement at O_1 you can write the equation T into b, T is the tension in the… this is called tie rod due to the weight here, you will have the tension in the tie rod. So T into b is equal to ws into a where ws is called the pan weight, by having different sets of pan weight and moving this, this is the poise weight.

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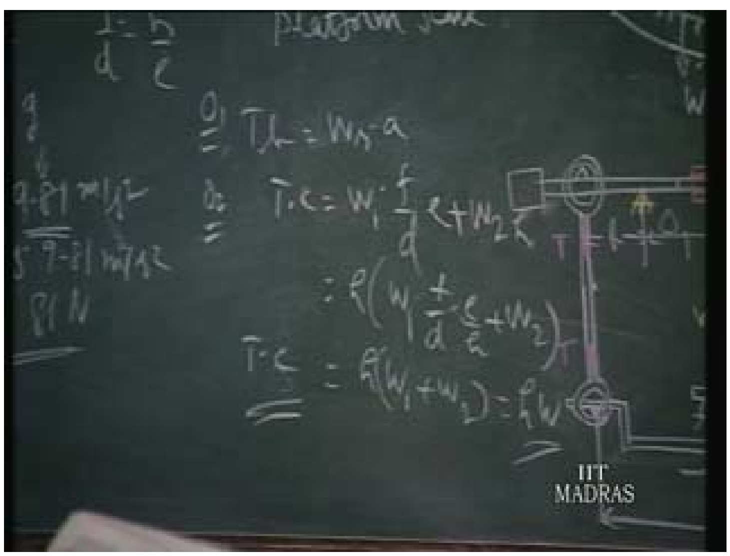

Suppose a lorry stands here then add number of pan weight and move this poise weight such that this end of the lever stands against the reference mark. Then you have measured, just add this pan weight and this reading here will give the total weigh of the lorry whatever it is that has placed over the platform that is the method of measurement.

So the principle is T into b is equal to ws into a and now taking moment about O_2, we can write T into c, c is the total distance that I have not marked there, total distance from this pivot to the other pivot. This is your c, that is T into c that is it is trying to tilt the lever in this direction clockwise. The other reactions tend to rotate the lever in the anticlockwise directions. That is two places two forces; w_1 part is w_1 into f by d. That is w_1 into f is this distance into whole lever this is simply supported beam, the reaction here will be f by d and that into e will be the movement about O_2 that is from w_1 from w_2 into h, it is simple w_2 into h, this is the motion.

Now taking h is a common factor then w_1 into f by d into e by h plus w_2. Now the lever edge of this platform scale is taken in such a way that you have f by d is equal to h by e that ratio we can easily select while you design. This way if it is selected then this cancels out, this equal to T into c is equal to h into w_1 plus w_2. W_1 plus w_2 is always w so h into w, so you find this instrument functioning is not dependent on the w and w_2, it depends only on the total weight. Hence we say this instrumentation is insensitive for position of the load. Now what we have seen is irrespective of the position of the load we get the correct measurement, the measurement doesn't get affected. Now what is this magnification or multiplication factor? For measuring a few tonnes of weight we use a few kilograms only. So what is that multiplication factor, we obtain by eliminating those from those two equations.

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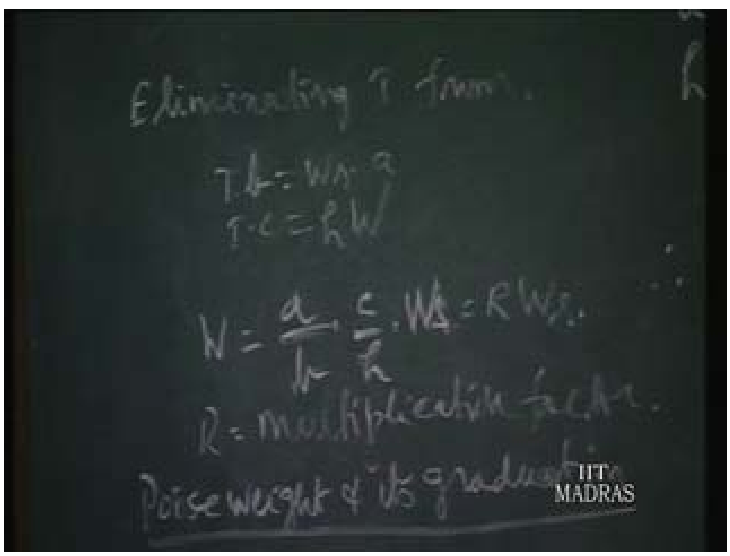

T into b is ws into a, we derived first that is the first lever and in second lever over O_2 we have got this equation. Eliminating T we have got w is equal to that weight, what measure is equal to a by b into c by h into ws. So all these things we call it as R so R into ws, so R is our multiplication factor. So that is if you measure 110 suppose 1000 kilogram force, if multiplication factor is 100 then by having 10 kilogram weight here we can measure 100. That is the advantage, by having a smaller weight we measure a very large weight. So that is pan weight but how the poise weight is decided? How it is made use of? Normally pan weight is added for every 10 gram or every 100 kilogram, suppose it is 1000 every hundred kilogram of weight we have to add one pan weight and in between say 100 to 200 we have to move this poise.

That is how the measurement is made use of by using this compound balance between the pan weight, if the weight is there however to that extent we are supposed to move the poise weight. This is poise weight. How the poise weigh is decided and pan weight is decided? This is an example here. Suppose a is 78 mm, b is equal to 13 millimeter, c is equal to 80 millimeter, i is equal to 6 millimeter, w_{max} 100 kilogram. That is the maximum load here, I assume it as 100 kilogram we want to measure and in this example so R is equal to multiplication factor is 80 that means the total weight what we have to put here is 100 by 80 that is 1.25 kilogram that pan weight we should have total.

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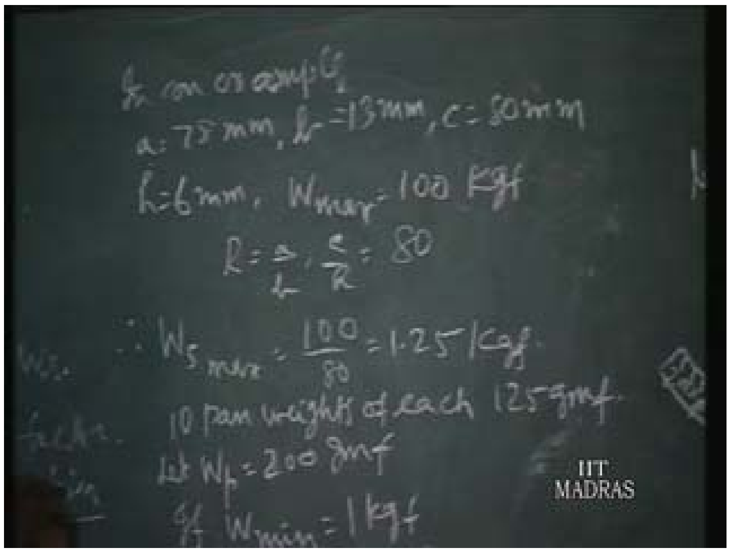

Suppose we want to measure here for every 10 kilogram weight we want to put one pan weight then that each pan weight should measure 125 that is 1.25 by 10 pan weights of equal weight, 125gram. If that is the pan weight then in between measurement we should have a poise weight which should be little larger than this one, so that it does not move over this from its movement. So when it is zero it will be standing here, at that position this is the counter weight. It is fixed in such a way when there is no weight here and put this at zero and no pan weight, only the holder will be there and we move it until the lever stands against reference mark and fix it there that is zero.

We have got pan weight for every 10 kilogram, between 10 kilogram say it 1, 2, 3, 4 or 11, 12 we do not measure. We should have for one kilogram force we should have the reading here. For that purpose let us assume here weight of one kilogram force here. That is w minimum assume as one kilogram force. What should be the poise weight here that we have to find out. So for that assuming a distance of x is moved with poise weight, poise weight being wp we move by distance of x for the next graduations. If x is distance for that say for one kilogram let us see later. If we moved like that then additional movement is wp into x that is being balanced in this side of the pivot. The other side comes from the one kilogram weight here that is we call it w minimum. So w minimum into h by c that is tension on the tie rod will be h w minimum, h by T is equal to T equal to see this side, into b will give the moment about O so that is why into b, w minimum h by c into b will be the moment in the other side.

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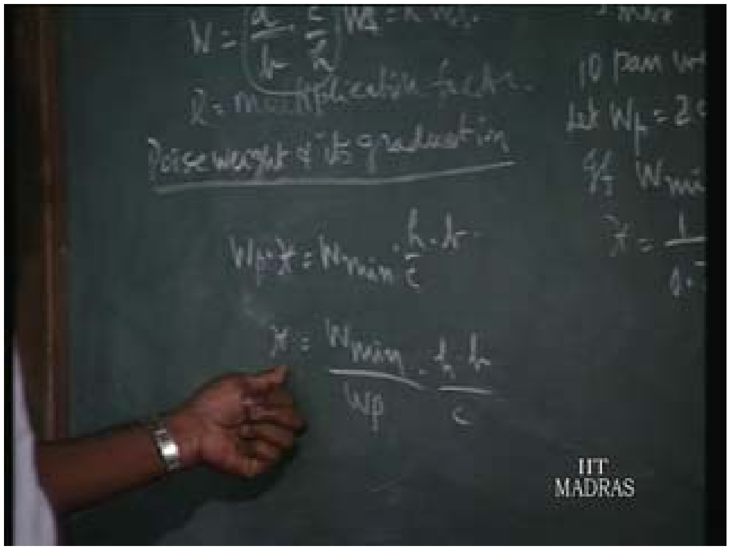

We equate these two motions. Due to the w minimum we have got the movement here and w p we have got this moment w into x. They are being compared and we find x is given by this equation w minimum w p h into b into b by c. Now for this pan weight of 125 gram we should have a little larger weight of poise weight 200 gram and for this w minimum 1 kilogram and x comes about 4.9 millimeter. So every 4.9 millimeter distance, you write 1, 2, 3 up to 10 so 10 kilogram means it will come here. That is how the poise weight and its graduations are finalized.