Chemical Principles 2
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Module 05
Lecture 27
Ideal Stirling Engine

So we have seen how Carnot engine works or Carnot cycle works, now we are going to discuss about some other types of engines, some of which are realistic engines.

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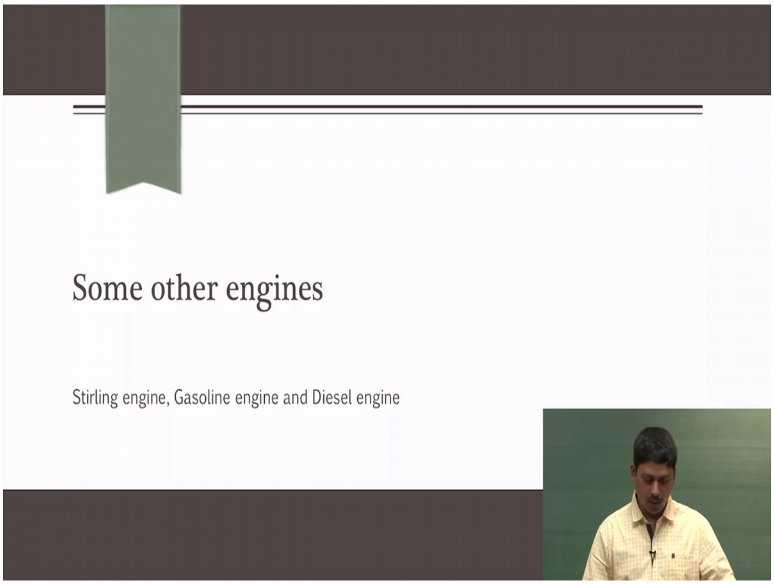

So among them today we are going to talk about Stirling engine, gasoline engine and diesel engine. We know that we have already talked about that the steam engine and Stirling engines are external combustion engines but as gasoline engines and diesel engines are internal combustion engines and we know that there are petrol cars and diesel cars, so in petrol cars typically gasoline engine works and whereas and diesel cars, diesel engine works. So we are going to talk about those things today those are realistic engines and we will see an equivalent ideal version of those realistic engines but we will start first with Stirling engine because that is something which has very similar efficiency and works in a similar manner as Carnot engine, however unlike Carnot engine is actually a realistic one and we are going to show that today.

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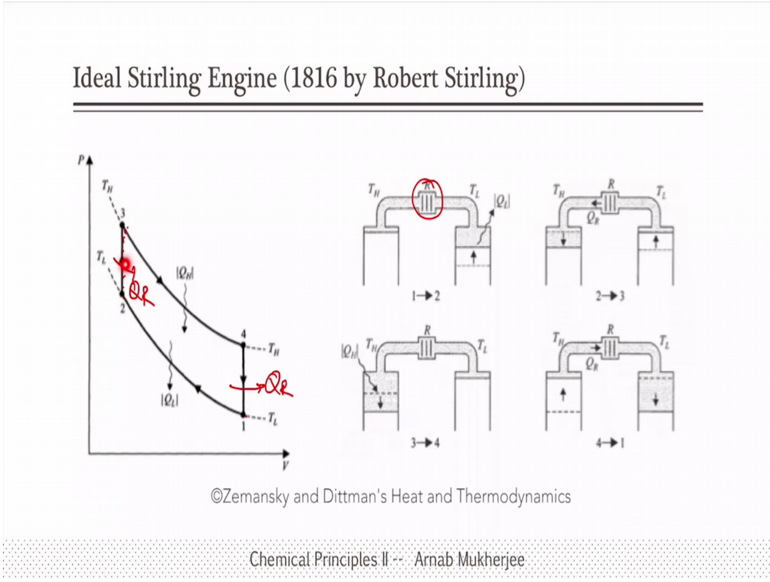

So here we are showing Stirling engine cycle for an ideal system assuming that there is no losses due to frictions and any other things, how does this particular ideal Stirling engine works? So it is very interesting to know that the Stirling engine came almost 8 years before they Carnot engine around 1816 where the Carnot cycle or Carnot (())(1:46) the Carnot cycle around 1824, so even 8 years before the Stirling made a workable engine.

The reason was that there was a steam engine before, steam engine came around 760s and there was lot of explosions in the steam engines, so in order to reduce that explosions the came up with Robots Stirling who is a priest came up with this particular design of Stirling engine and it had lot of advantages we are going to talk about that today, so an ideal Stirling engine basically has 2 pistons, so one is right side piston and another is like left side piston which is connected through something called regenerator R.

One of the pistons is in contact with high temperature heat bath or reservoir and another piston is in contact with low temperature reservoir, so it starts with let us say at point 1 where there is a change in the volume of the right side piston and this is filled up with some gas hydrogen or helium, so in the right side first the compression happens where the volume decreases in an isothermal manner from 1 to 2 as shown here and during that process heat gets released out of the system and then it comes to the point 2 where now the gas is in contact with the high temperatures reservoir.

So earlier the gas mostly was in contact with the low temperature reservoir and it got strung in an isothermal manner releasing the heat and then once it is strung in the second step the gas which is in contact with the high temperature reservoir gets heat from the regenerator which is inside the system but the ease a strinking of volume on the right-hand side and there is an increase in the volume of the left-hand side piston, so by that there is no change in volume.

In the third step which is here this is the power piston where there is an expansion in an isothermal manner from 3 to 4 where you can see that the gas which is in contact with the higher temperatures reservoir expands whereas the lower temperature reservoir it is same there is no change in that and in the last is step there is a decrease in the volume, since there is a decrease in this side and increase in this side the volume remains constant.

Now see that then these 4 steps in 1 to 2 there is an isothermal compression therefore it goes out of the system and in 3 to 4 there is an isothermal expansion so the system take heat from outside, however in the other 2 steps from 2 to 3 and 4 to 1 this is…2 to 3 is actually is isochoric process. Ideally these isochoric process would require a lot of thermal reservoir in order for it to be reversible because the temperature is changing at each step up the way, so in order to make it reversible it has to be attached to several infinite number of thermal reservoir at different temperature, however an ideal Stirling engine is designed such a way that the 2 to 3 the heat is taken from the regenerator.

So that QR which is taken here there is a heat taken from the regenerator which is this one and in this type the heat is released to that regenerator between 4 to 1 and regenerated is typically a (())(5:48) and therefore it can observe the heat and release the heat, so this QR the same amount of heat between this 2 to 3 and 3 to 4 is done within the system itself, so therefore no heat is taken or given out in this particular 2 steps.

This makes the efficiency of engine which am going to talk about is almost is exactly like Carnot engine because it works within 2 temperature reservoir one is the TH and TL and we are going to show that the efficiency becomes exactly like Carnot engine if there is a regenerator here. If there were no regenerator here then what would happen is that? The heat has to be taken from outside and therefore the efficiency will be reduced because then it will no longer be a Carnot engine.

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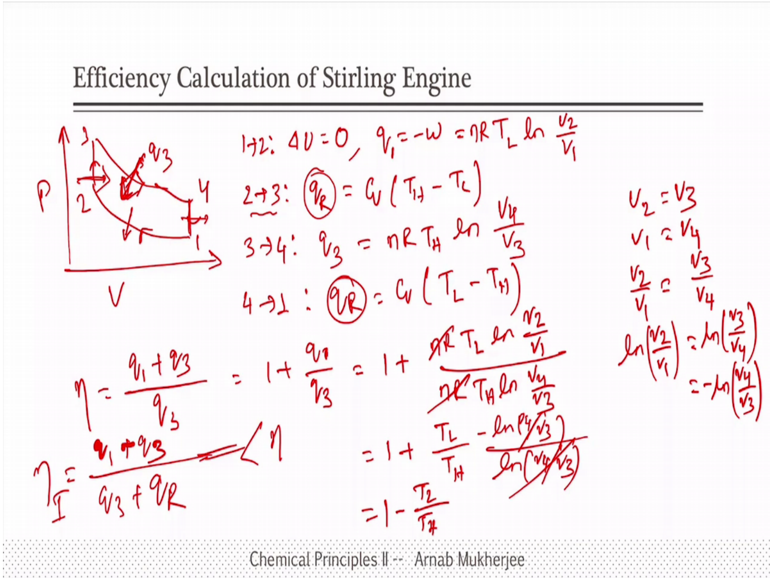

So we are going to calculate the efficiency of the Stirling engine, so this is a PV diagram it is an isothermal step, isochoric step isothermal and isochoric 1, 2, 3 and 4. So 1 to 2 is an isothermal compression process and we know that in isothermal compression process delta U equal to 0 and Q equal to minus W which is nothing but NRT L ln V2 by V1. In 2 to 3 step it is actually isochoric process, so in an isochoric process that heat, we call that first one as key 1 which is the heat that goes out of the system and this is an isochoric process QR which is CV.

So QR will be CV because it is in constant volume process TH minus TL. 3 to 4 is isothermal expansion again let us call it Q3, this is the place where the heat will go in inside the system q3 equal to nRT H ln V4 by V3 and 4 to 1 will be again qr cv T L minus T H, so you see that in the second to third step the amount of heat is exactly the same as but negative in sign as 4 to 1, so they will exactly cancel each other if that is taken from within the system itself and regenerator is part of the system itself, so although the system takes heat here and rejects heat in this particular step nothing is coming out of the system.

So if I calculate the efficiency with the regenerator then the total change in heat is Q1 plus Q3 and heat input is coming only in the 3 to 4 step which is Q3 which will be 1 plus q1 by q3 that means 1 plus…now q1 is nRT ln V2 by V1 q3 is nRT H ln V4 by V3, nR cancels each other 1 plus TL by TH and we know that V2 equal to V3 and V1 equal to V4, so therefore V2 by V1 is equal to V3 by V4 and therefore ln V2 by V1 equal to ln V3 by V4 equal to minus ln V4 by V3. So therefore there will be, we can exactly right that minus ln V4 by V3 by ln V4 by V3 cancels and we get 1 minus TL by TH.

So this is an engine which works between 2 temperature reservoir TL and TH and it is exactly same efficiency as that of the Carnot engine, so this is a realistic example of a Carnot engine which came into (())(10:33) even before Carnot proposed the engine itself. Now you see that if the regenerator would not be there then your efficiency would be that q1 plus q3 is a total word done divided by the heat input that is there in the q3 step class qR because in this step also heat has to be taken in and in this step also and therefore because the other 2 heat processes q1 minus (())(11:06) cancel in the numerator and therefore this will have lesser efficiency let us call it like efficiency of irreversible Stirling engine which will have lesser efficiency than a reversible starling engine.

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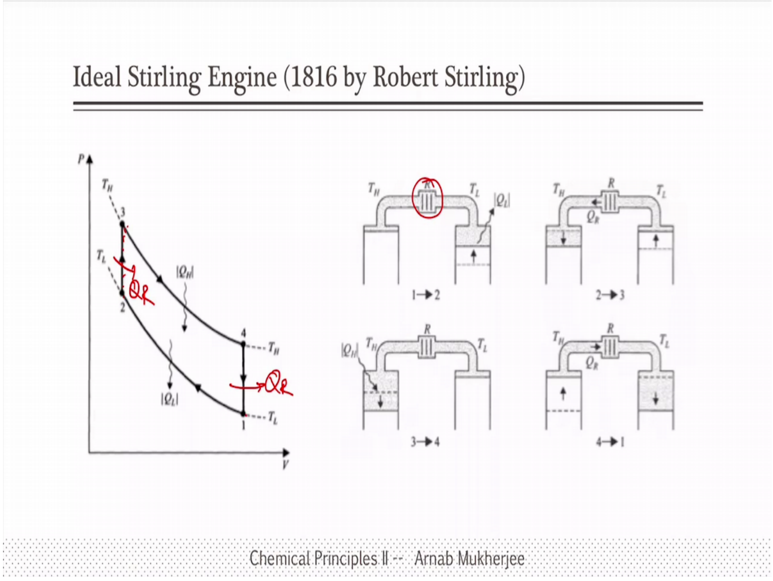

Okay so now we are going to show you a realistic starling engine which however has instead of 2 pistons like this shown here it has only one piston and this is the typically Stirling engine model that are sold and we have also one of that with us, we are going to show you that, so but before we are going to show you that I am going to explain that with the help of a picture, so the Stirling engine typically has few important components.

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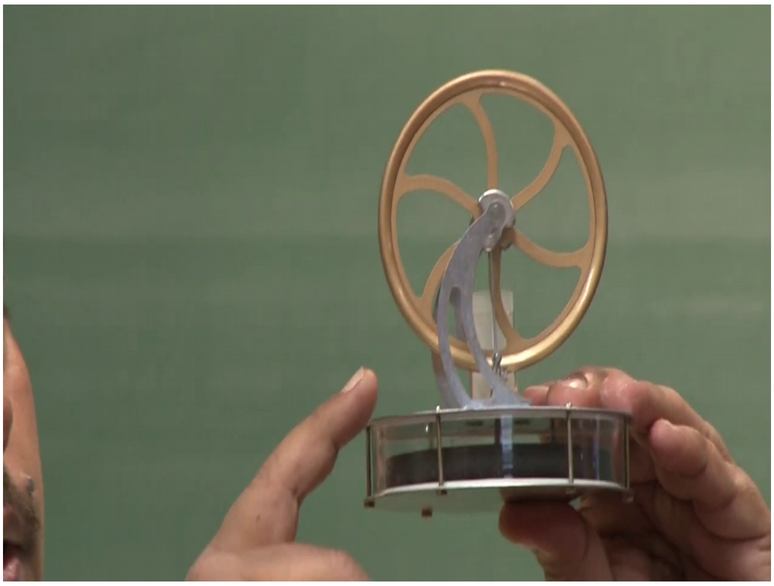

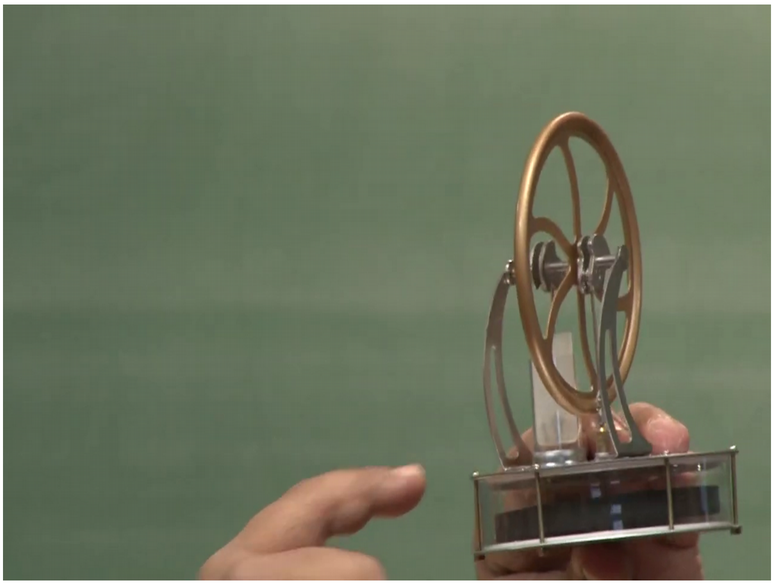

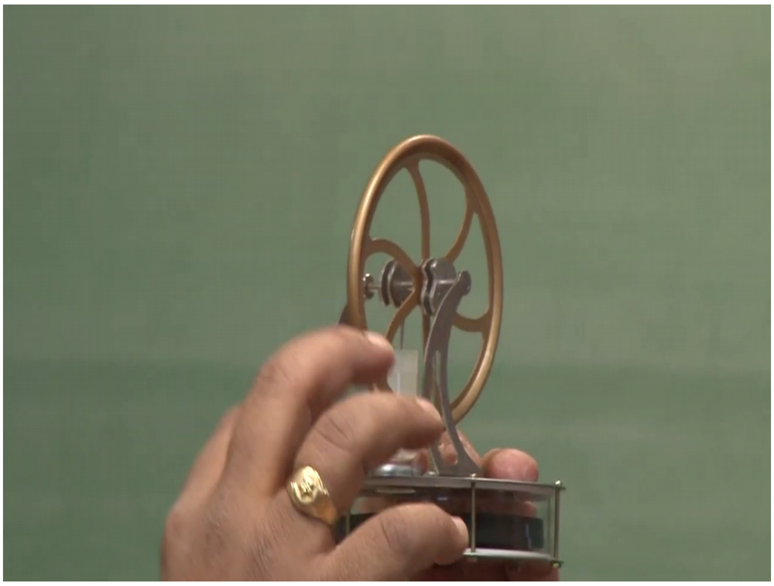

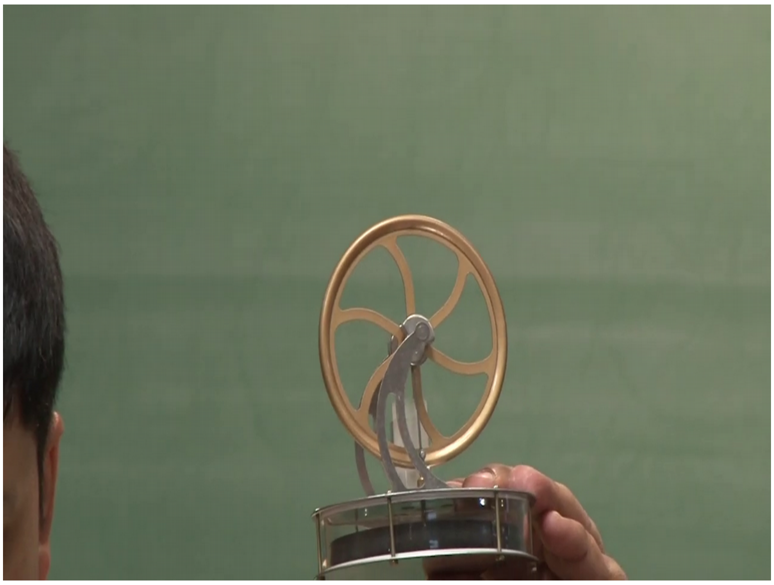

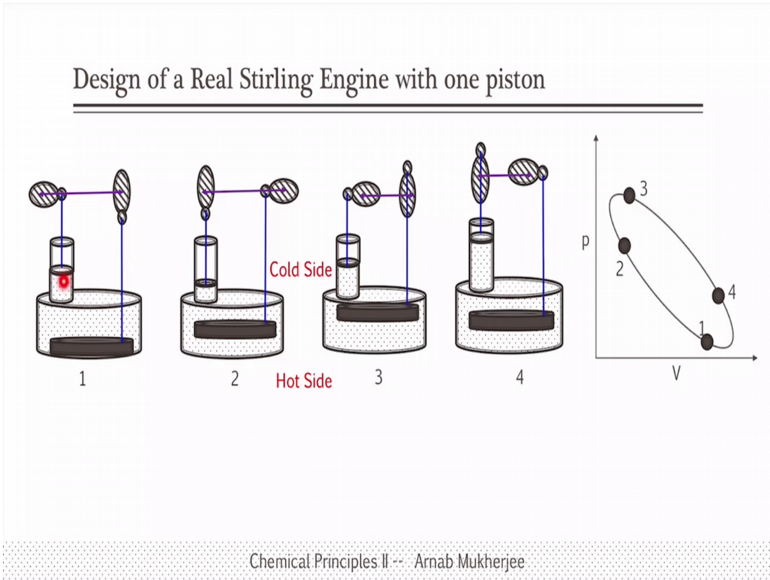
Design of a Real Stirling Engine with one piston
Cold Side
Hot Side
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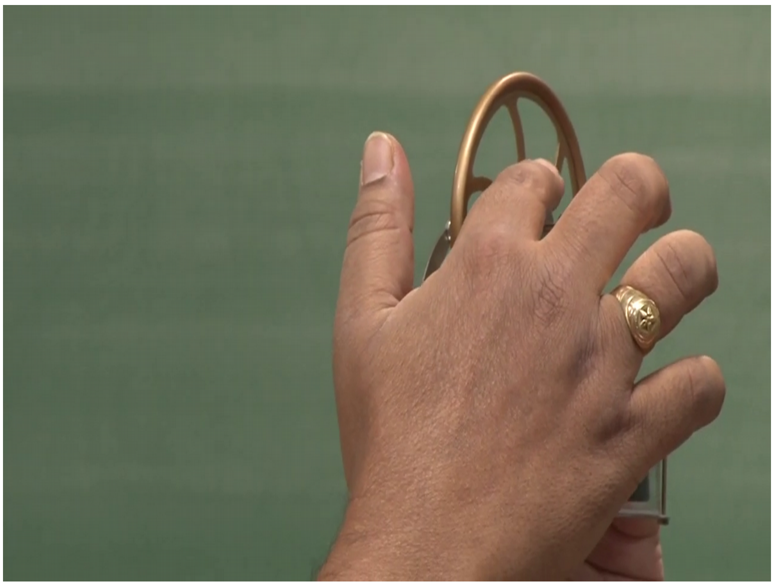

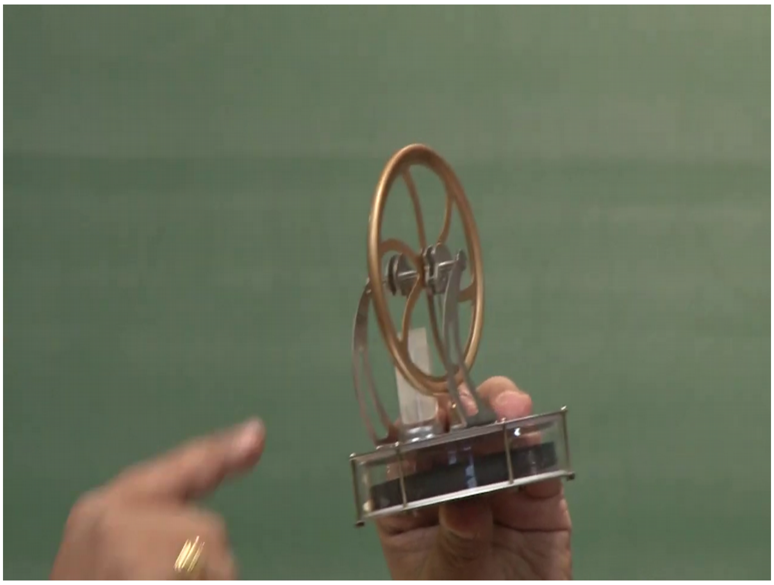
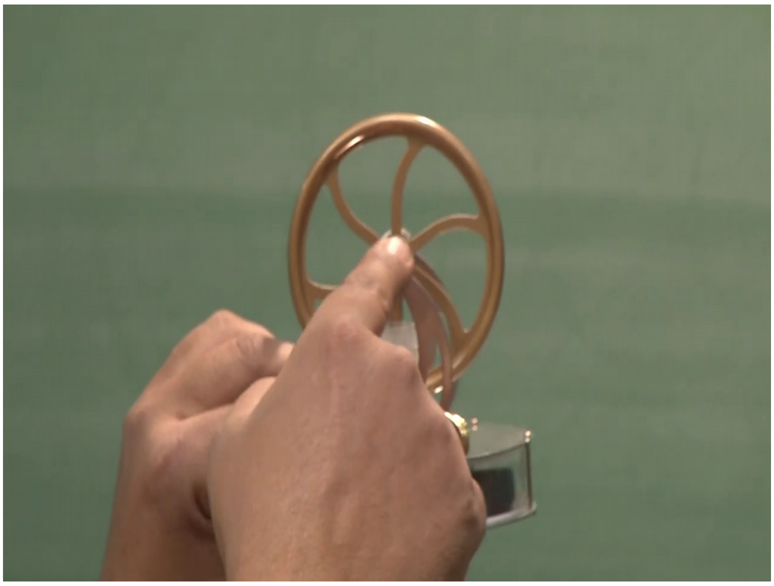
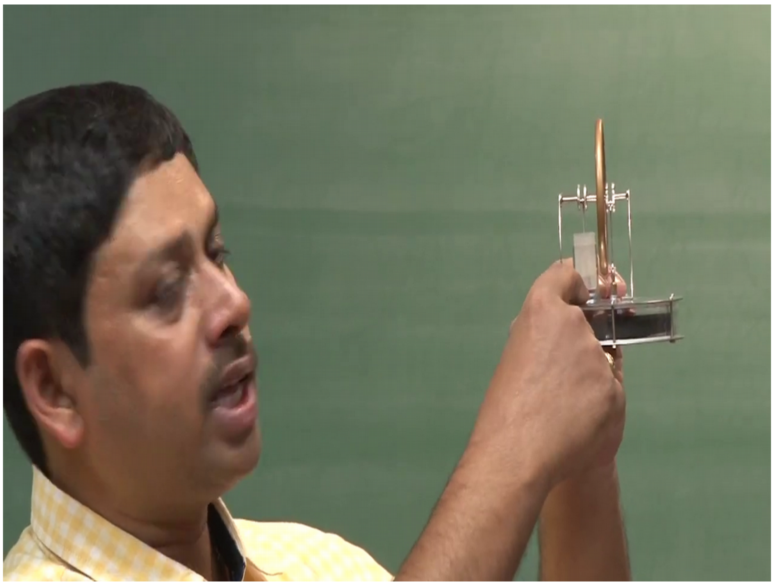

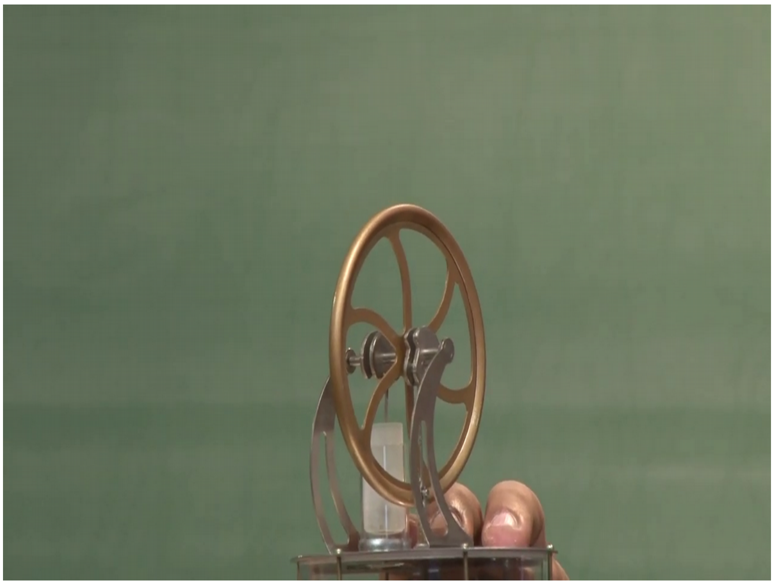
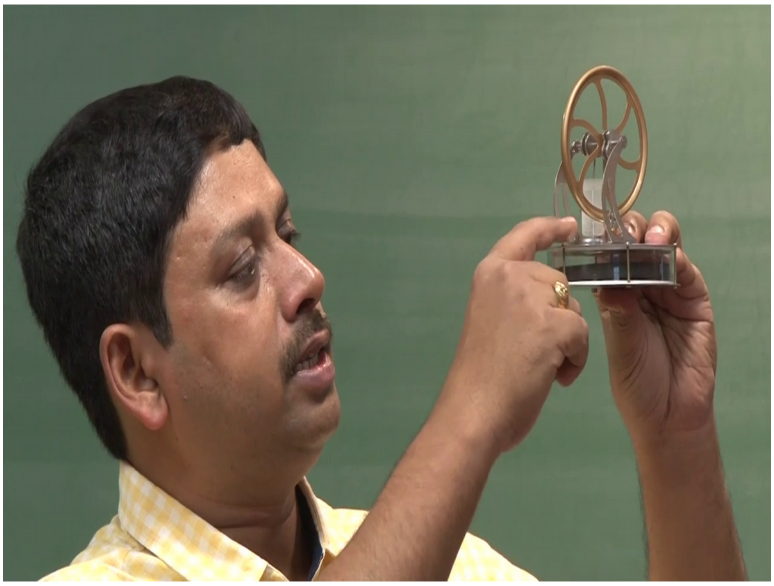
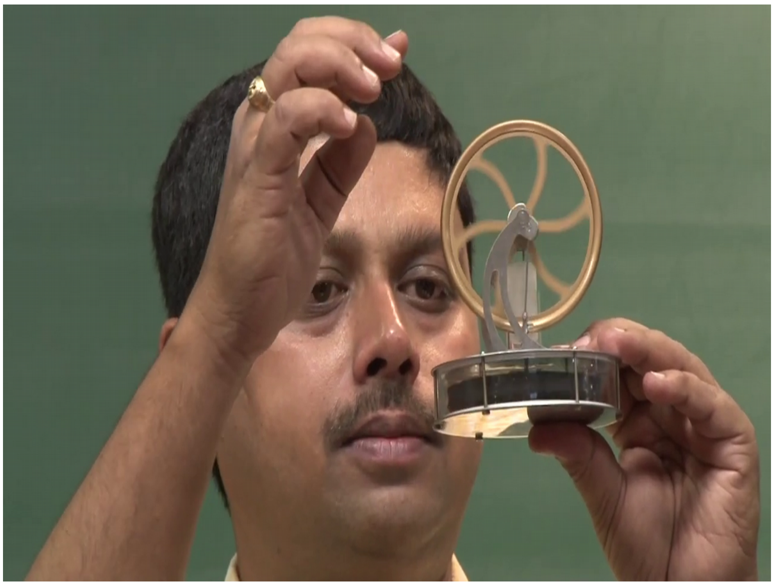

So this is an example of Stirling engine model as you can see there is only one piston here and there is displacer which is made of form which is here inside. The whole thing is sealed there is gas inside this system and you can look at here is that so this is the piston that I have drawn one most important thing is 2 cranks one is here crank shaft and another is here and you can see that they are 90 degree apart. Right now this is down here just like in this configuration number 1 and this is perpendicular to the other one which is like this. I have joined the 2 in order to denote that they are connected, if this one rotates the other one will also rotate.

Right now the volume is some midway as you can see there is a small gap between the white coloured thing and in the bottom there some gap, so this is in a midway situation and the displacer is down. Now what is going to happen is that Stirling engine works as I said based on temperature differences, the temperature difference can be created by putting higher temperature in the lower plate and lower temperature in the upper plate or the other way round lower temperature in the lower plate and higher temperatures in the upper plate.

So basically we have to create a temperature difference, the temperature difference can be either side. Now, but we have shown here picture in order to mimic something where the temperature is coming from the bottom For example like now the displacer is down and the piston is midway and once the system gets heated up…so now what will happen is that most of the gas is in contact with the low temperature, so therefore what is going to happen is that it is going to shrink, so this is the way so from your side it is clockwise so it is going to shrink, so in the second step as you can see here and once it shrinks the volume the displacer comes in the middle as you can see in the picture and you can see in my model also.

Next what is going to happen is that now the gas is in contact, some of the gas is in contact with the hot plate, so therefore and it is going to take in the heat and keeping the same volume the pressure is going to increase which will push it further and in the next step the displacer is going to go to the top pistol is again going to go to come in the middle. Now in this step most of the gas is in contact with the hot plate, so therefore it is going to expand now, once it expands you can see the piston has moved up, so this is the power part of the whole cycle.

So this is an isothermal expansion that is going to happen and which again will move, so now movement of the piston is actually moving this particular cranks shaft arrangement and this is again connected with the displacer, so the moment of the piston causes the wheel to rotate which in turn causes the displacer to also change at the same time, so the displacer is changing because the piston is going up and down that is first important thing and secondly the power part of the piston where it actually pushes up and let us say rotate helps to create the momentum which in turn makes the complete cycle and we have shown here that the PV diagram looks like an ellipsoid where 1 to 2 is the step of isothermal compression and then 2 to 3 is like a constant volume process almost and then 3 to 4 expansion will happen and 4 to 1 is again the constant volume changes but it is not an ideal engine.

So therefore it is exactly not like constant volume thing okay. So now we are going to show you, we are going to put it on a hot water below and we are going to show you that from your side it is going to rotate in this direction okay, so let us do that. You see from your side the piston is on my side, so the way we have put it the piston is on my side and in that case it is going to rotate in the clockwise direction.

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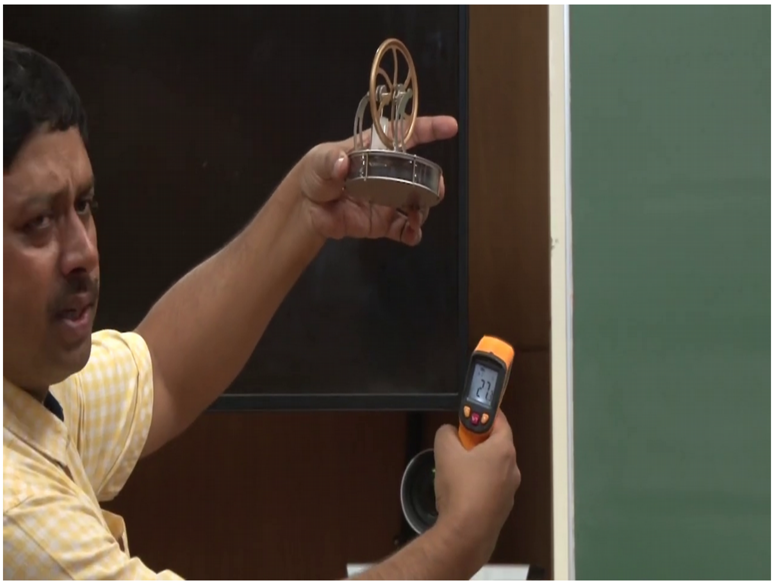


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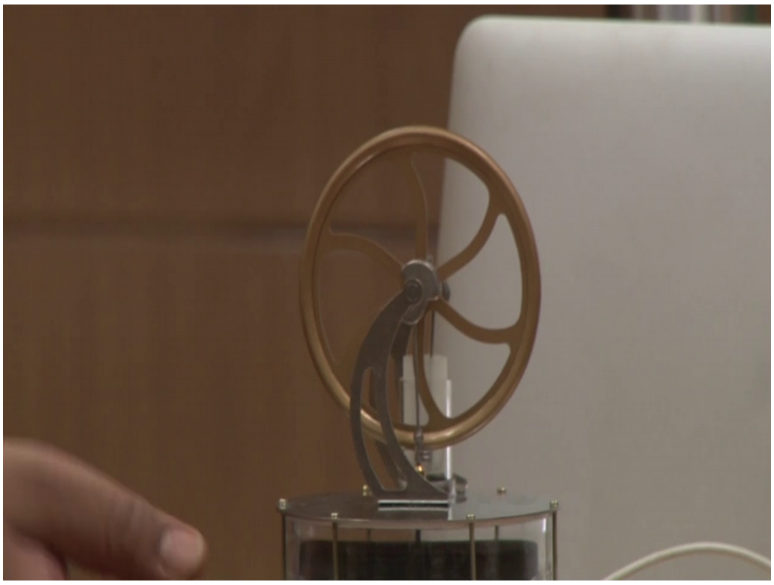

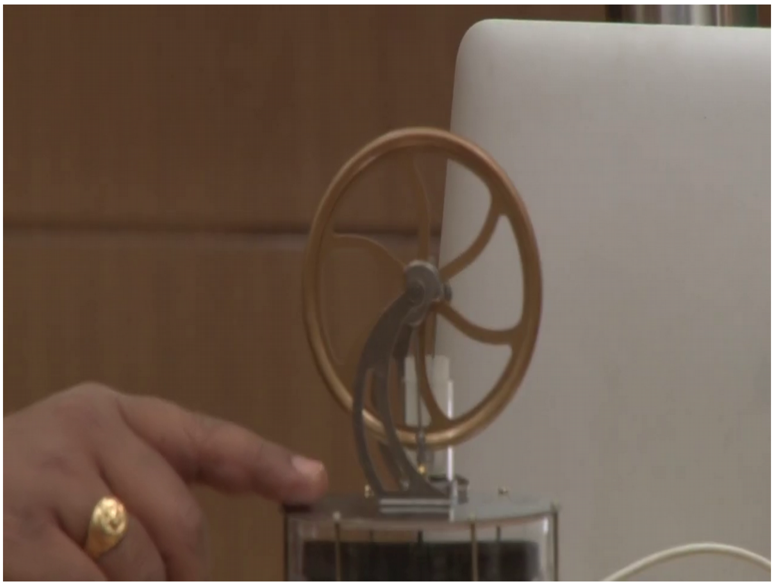

So before I show you that we are going to also calculate also measure the temperature of the 2 plates. It is fluctuating between 24 and 27 things like that. Let us see the bottom plate, bottom is already little bit higher 27.3, now let us put the hot water we have hot water here temperature of the water is 70.7 degree, now I am going to put the plate remember I told you the piston will be opposite from your direction and in that case it should rotate clockwise. So right now this plate is going to get heated up, this is going to be cooler, so compression is going to happen first and then middle and then expansion will happen.

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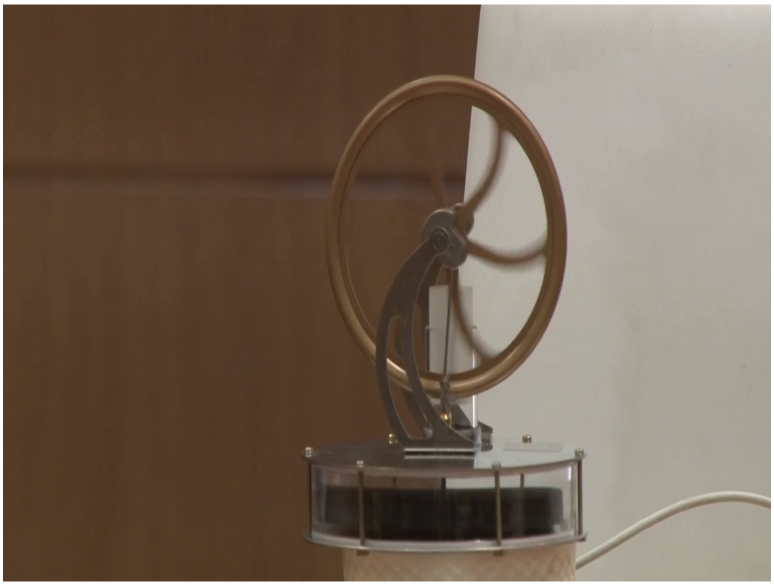

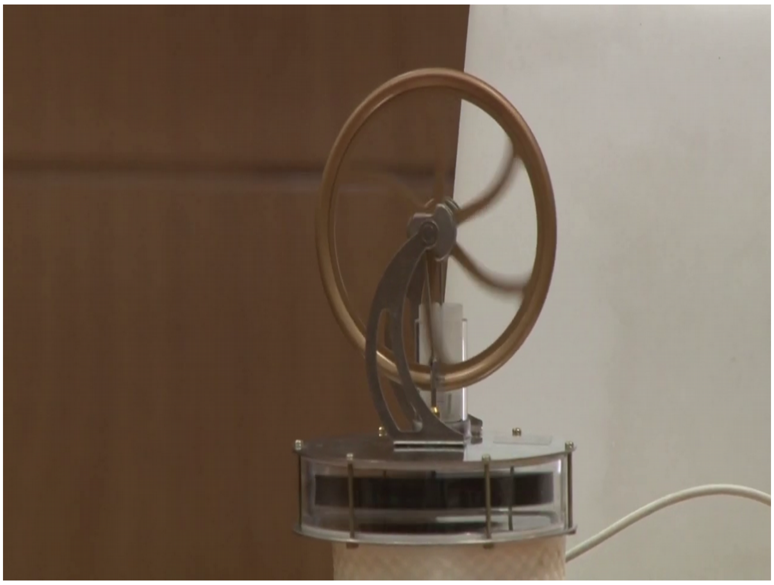

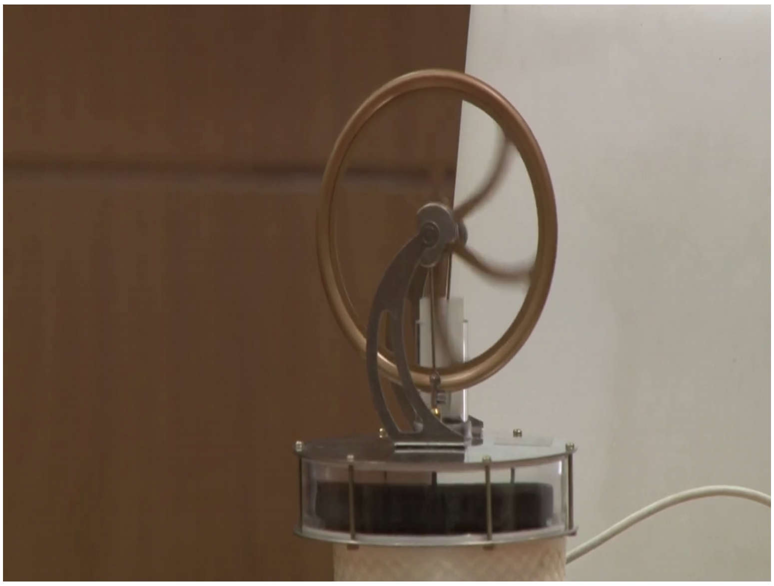

It has started, it is going to pick up the momentum as the plate gets hotter and hotter. Let it be there a little bit time, so you see unless there will be 90 degrees arrangement once this expansion will happen it will just get stopped because in that case all the gas be in the bottom only and the piston will be expanded form but just because the piston and the displacer are in a 90 degree shift arrangement so I can show you that while this video is playing that in the first stage what is happening is that.

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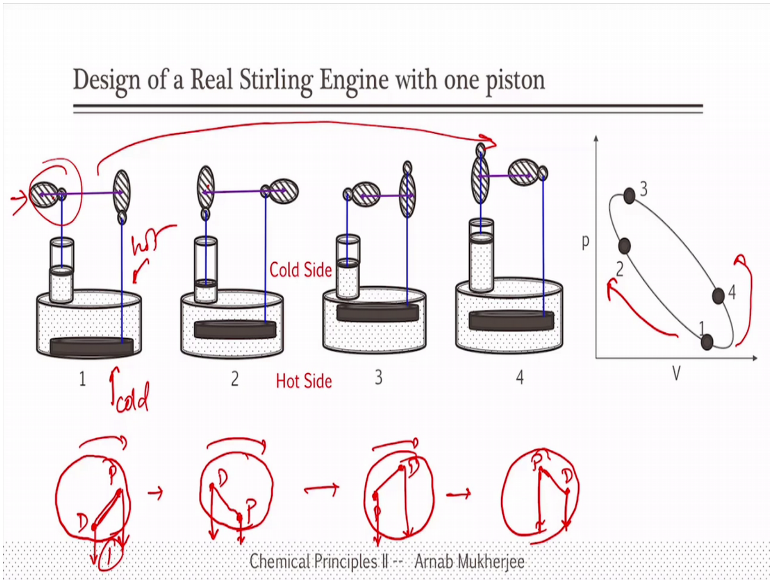

Now let us look at them angle, now in this angle the piston is in the middle and the displacer in the down place, so this is the place of the displacer this is the piston place and they are connected together. Now what is happening in the next step is that since it is getting cooled down this is number 1, in the second step piston gets lowered and displacer goes to the middle, so this is connected to the displacer this is connected to the piston, this is connected to the displacer connected to the piston.

Now you see there is a clockwise rotation happens, in the third step piston again goes to the middle but displacer now goes to the top and the last step. Now displacer goes to the middle again and piston goes to the top and that is the reason that whenever the piston goes up because of t displacer. If displacer helps the air to be connected to come in contact with the hot and cold air, so that is a very important part of the displacer. Another important aspect of the displacer is that it absorbs heat and gives away heat during the phase where there is a constant volume changes happens okay, so now if I change the hot and cold side what is going to happen?

So you see if I start with 1, so right now when the hot side is here and cold side is here then it is going on in… According to this diagram going on in anti-clock wise manner of course that response to this moment but let us say this side is colder let us say this site is colder and that side is hotter, so what will happen is that if this side is hotter the upside is hotter then it will expand, so that means from one it will directly go 4. So you know once that happens from 1 to 1 to 2 to 3 to 4 this rotation is an clockwise direction this one to this one to this one and clockwise direction but if it goes in the opposite direction 1 4 then it will rotate in the other direction.

See right now this thing is rotating in a clockwise manner but if this is colder and this is hotter then what is going to happen is that next step from 1 it will go to 4 expansion will happen, so 1 to 4 is an anticlockwise moment for this guy, so it is going to rotate in the opposite direction, so right now from your side when the piston is away from you it is rotating in clockwise but if I put in top of ice it is now going to rotate in the anticlockwise direction, so we are going to show you that and also one important thing is that if the flywheel is not heavy then also this rotation will not be possible because you need to have enough momentum for it to go over one cycle.

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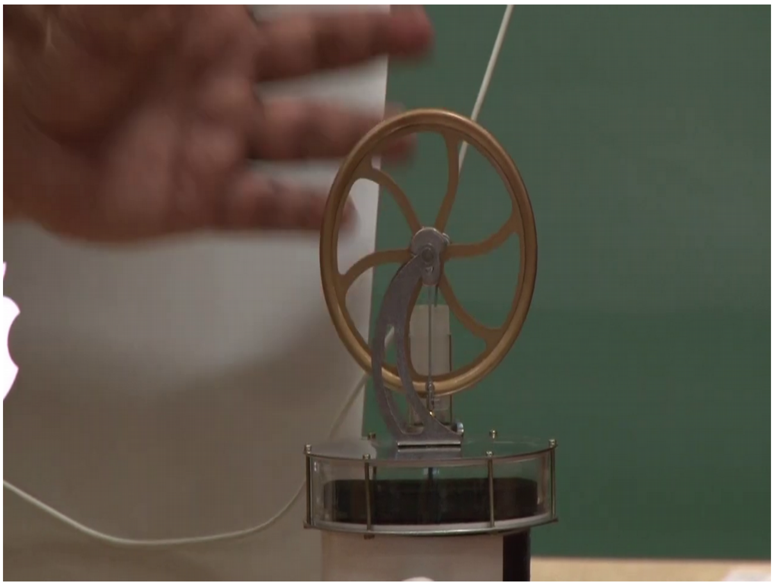

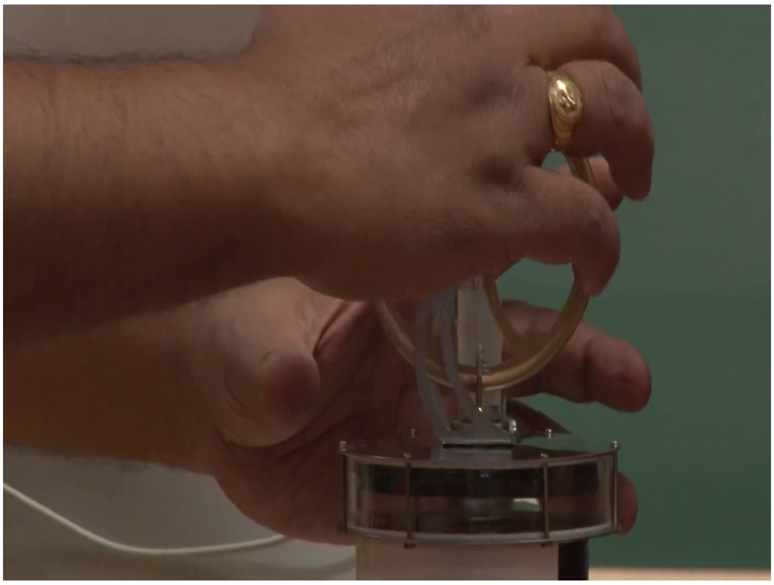
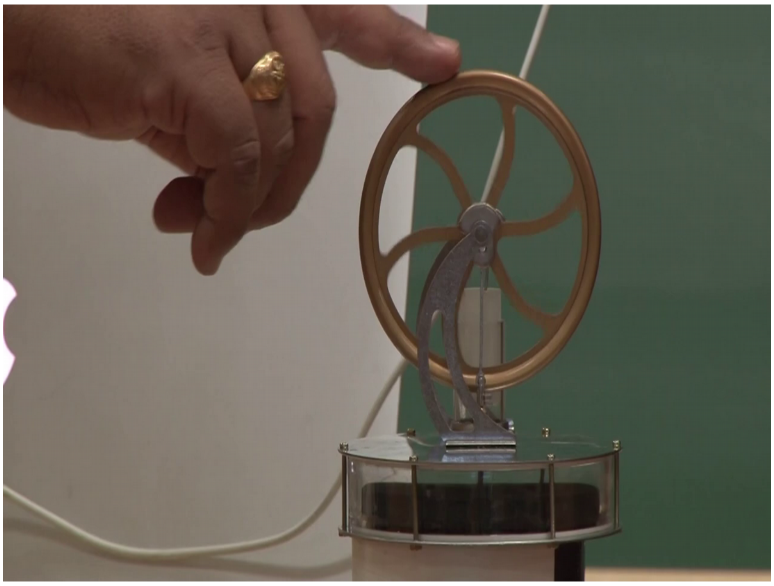


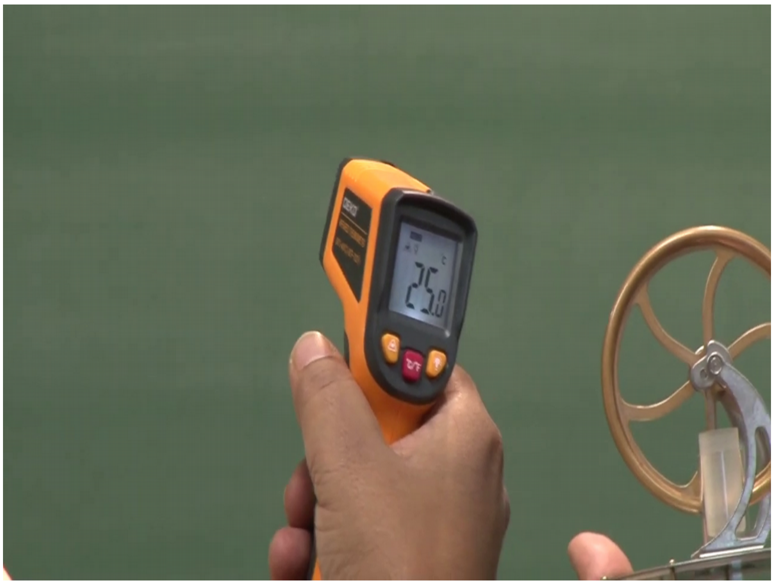
25.0

So there is an expansion phase that happening right that gives certain rotations of the wheel but in that if you have enough momentum then you can cross over the next part of the cycle and that is where you need some momentum on that. Now we are going to put it on the ice it is already slow down now you saw that there was a clockwise rotation you have seen. Now you see now it is going to have anticlockwise rotation I am going to give you a clockwise rotation just to see whether it happens or not but it is not happening, so let us give it anticlockwise rotation. Let it get down because the plate was hot right now we have now change the direction of the temperature.

Now the temperature was flowing from bottom to top, now the temperature is going to go from top to bottom top plate to the bottom plate while it is just getting cool down one interesting thing about the Stirling engine is that it does not eject anything unlike steam engine or gas engine and all that the gas is contain in a particular space and it is soundless, however it does not give enough power because in order to get the power that is required for let us say running a car or other bigger machines it will require much larger system much larger engine and therefore…but people are trying to make it better and another interesting thing is that whenever there is a temperature difference for example these computer generates huge heat and a.

So let us say one can manipulate and put a Stirling engine to take the ejected heat out of these computers and throw it outside in the cool environment let us say Norway or somewhere wherever the temperature is very cold but inside it is heat up there one can use that and then you can use Stirling engine to extract more this thing from except walk out of that. So now let us try that anticlockwise direction and you can see it is working in the anticlockwise direction slowly because the temperature difference is not that great earlier the temperature difference was 24 to 70 which was almost 46 degree difference but here the difference is 24 to 0 which is like 24 degree difference.0

So larger the difference is we have seen the efficiency is going to be more and more depending on the difference of TL and TH efficiencies going to change. Now you see from your direction when the piston is away from you it is now anticlockwise rotation is happening where as in the case it was happening in a clockwise direction. So just one more important point that I would like to make is that in the Stirling engine we saw that heat transfer from low to high moves the wheel that means heat gives rise to work but and eventually what is going to happen is that the temperature difference is going to decrease between the 2 plates and efficiency is going to reduce slowly because heat is constantly taking in and leaking out from there unless we maintain the temperature difference is going to come to the same.

Now I have put it for long time on top of ice just going to show you the temperature 24.9, 25.0 way similar temperature difference and we saw that the wheel stop. In the same manner in which we have put the heat and did the work we can do the other way round we can actually do the work and create the temperature difference just opposite of work to heat and heat to work as we know that right the energy is conserved, so right now if we do that for long time I do not know how long we have to really try.

If we do that for a long time this is going to create a temperature difference, so right now can you tell me like whether the top plate will be hotter or the bottom plate will be hotter? I am moving it in the direction where… Clockwise manner yes, so if we do that the bottom plate is going to be hotter because that the flow of heat has to be from here to here in order for it to rotate in the clockwise manner but probably we have to do it for a long time.

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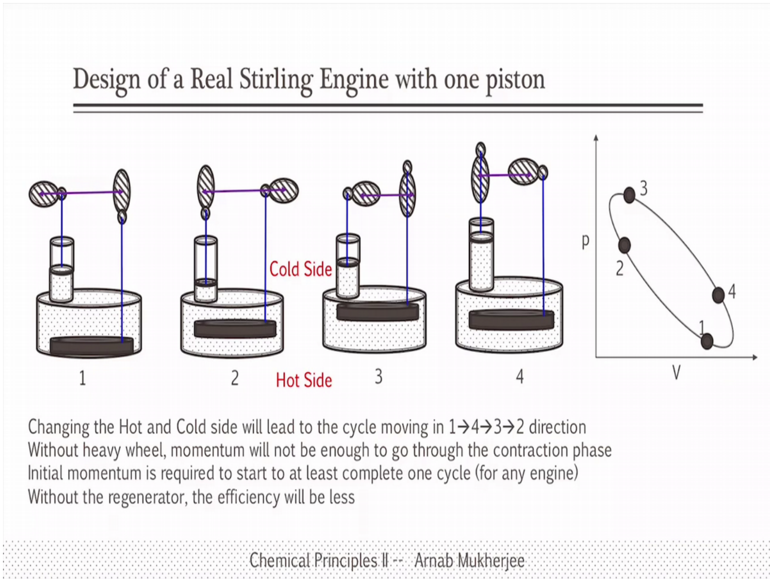

Yes, so as I said that changing the hot and cold side will lead to the cycle moving in 1, 4, 3, 2 which is currently happening now without heavy feel the momentum will not be enough to go to the contraction phase, so there is expansion there is contraction. Initial momentum is required so if you just put it on top of hot plate or cold plate if you do not touch the engine it will not work at least you need to give an initial momentum because the situation is like that the system is not always kept at 3 such that in the first step itself you will get the expansion to 4 typically it is somewhere in the middle.

So therefore you have to give a push to at least cross one cycle once. Once it crosses one cycle then for the subsequent cycles the heat that is taken in between 3 and 4 will be enough for it to go over the cycle and without the regenerator as I said the deficiency will be less, so this particular engine has lower efficiency compared to an ideal Stirling engine which has… Of course this has lower efficiency for many other recent because it is a realistic one, it has frictions and it has many other things it does not have an ideal gas and ideal expansion and all that, so a typical engine, a realistic engine will always have lower efficiency than the ideal engine but the interesting thing is that while Carnot designed this particular highest efficiency engines Stirling already had made a design and engine which works and that has a semi-efficiency as that of the Carnot engine.