Dynamic Behaviour of Materials
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Lecture-21
Equations of States (Shock Waves) Experimental Methods

Hello everyone, so in the last lecture we discussed about shock waves and shock waves we worked on some numericals and graphical techniques of solving some problems with impedance matching technique. And in this lectures we will focus on the equation of states of shock waves, so first we will discuss some experimental methods and then we will have a brief overview of the theoretical calculation of equation of state.

So equation of states as we know that the relation between shock parameters like we found the relation between shock wave velocity and particle velocity and such type of relations are that we call equation of state.

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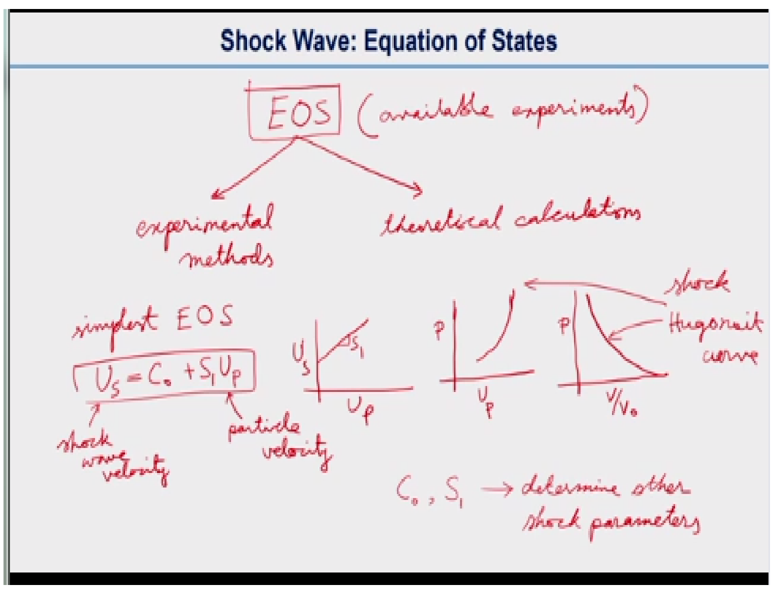

So the equation of state we can obtain we write it as EOS that we know EOS equation of state for shock waves. So there can be 2 ways to obtain these equation of state first one is experimental methods and then we can have some theoretical calculations as well. So equation of state the simplest equation of simplest form is we found that the linear relation EOS = C0 + s1 U p, the

EOS is the shock wave velocity and that we already discuss shock wave velocity and this is the particle velocity.

So this is the simplest one and equation of state also can be we can have actually we plotted this one earlier that we note that EOS verses U p that is a linear relation. So which has slope s1 and there can be some other relations also we had pressure versus particle velocity which we have from plot like this for some material and then the another one is phases versus the specific volume which we have drawn curves like this.

So the equation of state data available even if you go through the textbook you will available from experiments, go to the textbook you will get couple of tables where these EOS data the parameters are the mentioned in tabular form. So many of the materials we already know the equation of state but some of the materials we may need to find the obtained EOS that relationship between these parameters, so and also we have termed this as Hugonoit curve.

So if you remember which pressurizes specific volume this is from this is Hugonoit curve or shock Hugonoit. This equation of state in and is actually can be called as a Hugonoit curve shock Hugonoit curve, so for this also we can call these curves shock Hugonoit curve for this particular material. And also we discuss that if we know the suppose from this simplest form of EOS if we know the parameters c0 and s1. Then we can determine the other parameters, determine the other shock parameters.

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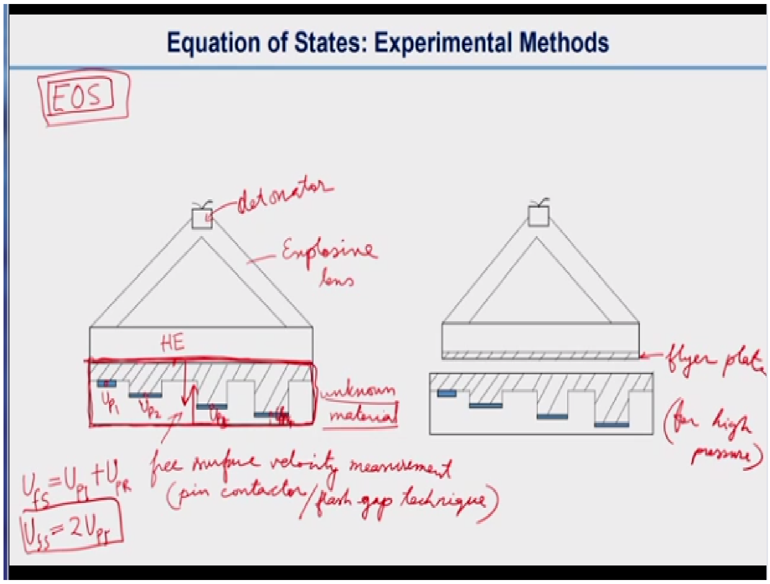

There are several methods to obtain the shock parameters, so we will just briefly discuss these experimental methods. So these are older techniques to obtain a the EOS there a little variation here in the case 1 and case 2. So we have the material, this is the material unknown material, so this is our target say we have a detonator here so what our goal is to obtain the EOS for this unknown material.

So this is one experiment this is we have high explosive here and with the help of this detonator will explode it and we will see the response of this unknown material. So and this is a arrangement called explosive lens that is use for plane wave generation, so basically so we will go through it very briefly we will go to and because we discuss the other method as a gas gun method in details. So here what will have we will have some in this unknown material we will have a free surface velocity measurement using pin contactor.

These are some arrangement for to get the free surface velocity, so we can get the shock wave velocity of particle velocity here. Pin contactor or there is another method called flash gap technique, so if time permits we can discuss this later in another chapter. So basically with the free surface velocity measurement what we can get it as that this free surface, so if we can measure the free surface the particle velocity we see that suppose this shock wave and generated from the top side of this unknown material will come this way.

And then will reflect back from this free surface, so then these are actually this is taken from the diagram of Mark Meyer's book. So these the points of particle velocity measurement at different points we have different particle velocity Up, 4 Up, so now what I wanted to discuss the part free surface velocity is equal to particle velocity incident on this free surface + the particle velocity is reflected.

So then which will be reflected particle velocity will be we earlier discuss these things the particle velocity will be equal to the incident one. So this will look like this, so what we can do is we can get this or I will write it rather write it here, so yeah so basically this is Ufs will be twice particle velocity incident well velocity that will be reflected back from the free surface, if we have these values of particle velocity and the shock wave velocity.

Then we can get the equation of state, so similarly here we have a flyer plate and this is a very similar arrangement but with a flyer clip sometimes if the pressure is very high this arrangement is helpful, so for high pressure for very high pressure. So this right hand side arrangement is more convenient, so this is one method.

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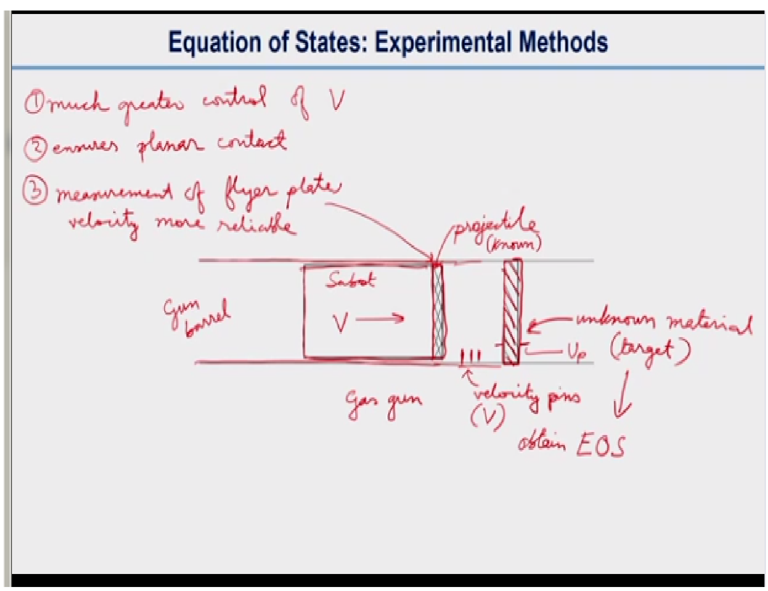

But then we will go and discuss this method because this method is more convenient and then the earlier method, so this is a gas gun system, so this is the gun barrel. So you can see the gun barrel is this is the gun barrel so gun barrel and this is as you know from our earlier classes this we called sabot it is moving at a velocity V and this is the projectile actually this is we can call that projectile or whatever if you have maybe a flyer plate and this.

So the projectile is known, so we have a projectile of known material, so we know the equation of state of the projectile and here we have our unknown material that is the target material and that equation of state. This is our unknown material that is the target and so what we wanted want to know is the equations of state of this unknown material. So our goal is to obtained the equation of state of this unknown material.

So we will do with the help of this gun barrel or this gun system gas gun, so these pins are kept for velocity measurement the velocity pins. So that is actually will measure the projectile velocity V and then there will be some pins here itself also as well and problem under this surface these pins will give us the particle velocity Up and this gun system is more convenient than the earlier one.

And it has much great control over the control of impact velocity V and then it also ensures planar contact. If you see the earlier one was explosive hitting the target and that may not ensure a planar contact. But in this case it is we can say ensures the blade better planarity of the contact and one more point is measurement of flyer plate velocity is more reliable flyer plate is this projectile, velocity is more reliable.

So basically we have a control over this flyer plate velocity and also we can easily measure with a greater reliability we can measure this velocity, so that is 2 points. And then we will use impedance matching technique after these experiment, so this experiment will give us the particle velocity and the wave velocity.

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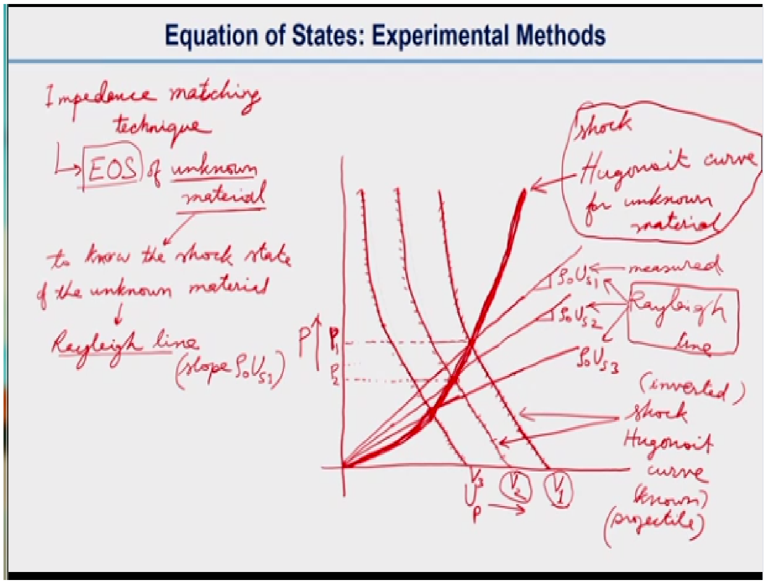

So we will use the impedance matching technique earlier we discuss about that matching technique. So what we will do in this case is, so this is particle velocity Up and this is pressure P, so what we will do is we will draw a curve which is our we call shock Hugonoit curve this is actually shock Hugonoit curve for the projectile that we know that is known material and that is actually the projectile that is known that is for the projectile.

So what we wanted to know from here from this impedance matching curve to we want to obtain the EOS of the unknown material that is our target material. So now we know this shock Hugonoit curve this is actually call as a inverted shock Hugonoit because that we discuss in the earlier class. And this is because the velocity will decrease with increase in pressure here the particle velocity.

So that is why we use the over inverted shock Hugonoit here and then this is happening at a let us say impact velocity V1, the impact velocity V1 that means in the projectile in the particle velocity initially it will be V1 at the point of contact at a time of contact. And then it will decrease and the pressure will increase, now to know the shock state of the unknown material.

We can draw the Rayleigh line lines for this particular impact velocity V1, so we can draw one Rayleigh line which will have a slope of slope rho0 Us, rho0 is the density and Us1 we will write for one corresponds to the impact velocity V1. So we can do some more experiments with different impact velocities, so here the Rayleigh lines the typical slope will be Rho0 in Us1 that will give us we if we can draw the lines here it will be a straight line with slope.

This slope will be rho0 U s1 and this will give us the shock state of the unknown material at this pressure. Let us say this P or P1 pressure we can get the shock state of that unknown material but we want to know the entire shock Hugonoit curve for the unknown material not only at a single point. So that is why what we will do is we will or try this experiment at a different impact velocity.

Let us try it at a velocity V2 in fact velocity V2 and we will get another shock Hugonoit curve, so up for the at the known material the projectile and then again we will draw another really a line with the slope the different slope as we know that will correspond to the impact velocity. This will come from the origin that this line will have a different slope rho0 Us2 and similarly for pressure P2, so this point will give us a shock state of the unknown material target material at a pressure p2.

And then similarly what we can do is we can perform the experiment at a different impact velocity assume that this is V3 and in that case again we have a Rayleigh lines, so that Rayleigh line is this one this will rho0 Us3. So this point will give us the shock state of corresponding to that impact velocity V3 and so if we connect all these points here something like this I will make a thicker line.

So this is the required EOS or basically we will call it as a Hugonoit shock Hugonoit curve that is shock Hugonoit curve for unknown material. So what we found again we want to summarize this, so this is actually what we wanted to know is the equation of state of unknown material that is will be given by this shock Hugonoit curve with the thicker you know curve, so first what we did this is a pressure verses particle velocity.

And then first if you again want to remember this previous slide, so we did the experiment in a gun barrel which is sabot and flyer plate in front of the sabot this is we can call is a flyer plate and we have a target material which is unknown material for us. We need to determine the EOS or Hugonoit curve for the unknown material and we know the Hugonoit curve for the projectile that is known.

So now what we did is we first we have drawn this first I will just make it a this curve we first got this curve just to you know show you I just made this cuts on there. And this is the shock Hugonoit curves of for the known material that is the projectile at the impact velocity V1. Now again we did the experiment again at a impact velocity which is lower than that, so we will then find this curve this one.

And then similarly we did the third impact velocity as a different impact velocity and we got the cut this curves and these curves these all 3 curves these are shock Hugonoit this also was one curve the shock Hugonoit for the known materials. Now what we did is we did we have drawn some 3 straight lines corresponding to each of these impact velocity with a slope density multiplied by Us1 that means shock wave velocity this can be measured.

And we know that density is anyways can be measure density we know for the unknown material but what we do not know is the equation of state. So here for the Rayleigh lines ok I should write it Rayleigh line here Rayleigh line this is h, so these 3 are Rayleigh lines, so this is these 3 are Rayleigh lines. So these 3 have slope density multiplied by the shock wave velocity and then after that if we connect these intersection points of the Rayleigh line and the shock Hugonoit curve of the known projectile.

If you connect those points we will get the shock Hugonoit curve for the unknown material, so that is from the experimental methods to determine the equation of states of a unknown material for shock waves. And then we will discuss about some theoretical calculations also possible in few cases from the first principles or quantum mechanics formulation, so that we will discuss in the next lecture, thank you.