Fundamentals of Compressible Flow
Prof. Niranjan Sahoo
Department of Mechanical Engineering
Indian Institute of Technology, Guwahati

Lecture – 24
Shock Tube Facility Gas Dynamics Laboratory

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We are now going to demonstrate a Shock Tube Facility which is installed in the Gas Dynamics Laboratory of the Mechanical Engineering Department of IIT Guwahati. So, this particular shock tube facility which we cover in the course modern compressible flow and in the last module we have given all the theoretical details about the shock tube facility.

So, in the laboratory we have installed a shock tube facility it consists of a driver section and a driven section. So, as you see this driver section this is a high pressure section for the shock tube and they are connected by pressure regulator and subsequently it is connected to high pressure cylinders nitrogen and high pressure cylinder helium. But, in one of the particular experiments either we can connect it to high pressure nitrogen gas or high pressure helium gas. So, these two are the mostly used driver gases that are used for shock tube.

Now, the most important part of this driver gas is that if we are going to use a higher molecular weight gas in the driver section, then it will lead to less shock wave velocity or

Mach number. But, however, when you are going to lower molecular weight gas which is helium then we can have shock speed in the tube will be faster.

So, now, let us start with the driver sections. So, here in the driver sections there are two tubes of 1 m length and they are connected through the planes. This stainless steel tube is width of 56 millimeter internal diameter and 12 mm thickness and it is the and what you see here is the diaphragm that separates the driver section to the driven section.

What we can do now is that, if you look at this particular tube we have this driver section and driven sections and this metallic diaphragm we are going to put it in this manner so that the both driver section and driven section during the experiments can be distinctly separated. So, while performing the experiments we will tell you how you are going to connect it.

Now, another important feature of this diaphragm is that this particular diaphragm is made out of aluminum material and this is of 1 millimeter thickness. We can think of different thickness diaphragm if you want to increase higher shock speed. So, the diaphragm will ruptures with respect to its yield strength and when it ruptures, it has to rupture in a particular fashion. Then only we can say that a shock curve is generated.

What does this mean? It means that while discussing about the shock tube theory we have told that by pressurizing the driver tube we are essentially increasing the compression waves. And these compression waves are generated and at one particular time, these compression waves has to merge and they have to come as a shock wave.

Now, in this process of merging if you do not use a particular fashion of this diaphragm then this diaphragm can rupture abruptly. So, that is the reason we have made here a groove which is a V groove and this V groove as you can see it is pointed at the center and the section of this, is a V shape. And, the diameter of this size of this circle would be something of similar value which is the inner section of the shock tube.

So, when it fits it, we try to see so that this rupture has to initiate from this center point and when it ruptures here it will rupture instantly at particular pressure for which this yield strength of diaphragm is defined. So, this is the basic philosophy that the rupture pressure or instantaneous rupture of this diaphragm will generate the shock wave.

Now, one by one we will now move to the driven section of the tube. So, you see that the have driver section has two tubes each of 1 meter length and driven section similarly it is connected from this end or the separation point of diaphragm and there are 5 tubes connected in this sequence.

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Now, we are moving to the driven section of the tube. So, driven section of the tube is of similar length and material as used in the driver sections. So, as a thumb rule when we are using two tubes of driver section of 1 meter length, similarly we have to use minimum of 5 meter of driven section length.

This is mainly due to as it is explained in the theory that the introduction of shock wave also creates expansion waves; that propagates back into the driver sections and subsequently they reflect from the end flange and they interfere to our signal. So, for this reason as a rule of thumb we have been fixed that driven section tube will have 5 number of stainless tubes of same length and they are also connected in the similar fashion using these flanges.

Now, let us come to the measurement part. So, for the driver section and driven section the measurement part consists of two things. One is first thing we should know that at what pressure the diaphragms would rupture; that means, this particular aluminum diaphragm when it is fixed in the junction point at what pressure it should rupture.

So, to do that when you pressurize this through this gas cylinder, side by side we monitor the pressure at which it ruptures using this pressure gauge. So, that is a pressure gauge which is connected to the driver section or high pressure section. And, the similar way we also connect this driven section using a vacuum pump so that by switching on this vacuum pump we can reduce the pressure.

And, side by the side we can also monitor the pressure within this driven section of the tube using a simple manometer. So, this manometer will tell about the pressure in the driven section and these pressure gauge will tell us that pressure in the driver sections. So, we can say that this pressure will keep on increasing and once the rupture pressure of the diaphragm is reached, then again this value will come down.

Now, this is how the driver section and driven section pressure measurement is undertaken while during the experiments. Now, we will move to the subsequent measurement part in the driven sections. So, just to tell you that at this junction of time we say that at this location the shock wave we are going to generate. This shock wave is going to propagate in the driven section. And, this will keep on happening till this shock wave reaches in the end flange.

Now, when the shock wave is generated due to the instant rupture, the induced mass which is already there in the driven section of the tube, it will also follow the shock wave. So, as we have mentioned in the theory that we have a shock wave which is moving towards the end flange of the driven section and followed by induced mass.

And, the driver section and driven section is separated by a diaphragm and theoretically we call this as a contact surface.

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So, now let us move to the instrumentation side for the driven sections. So, we have seen that when the shock wave propagates in the driven section, across the shock wave there is a instantaneous rise in pressure of the induced mass. So, to measure that step response of this induced mass pressure, we have mounted two pressure transducers and one is at this location which is 1885 millimeter from the end planes.

Now for this, driven section is terminated with an end flange at this location. Now, from this end flange location, the first pressure transducer that the shock wave sees is at a location of 1885 millimeter from the end flange. And, there is another pressure transducer which is located at a distance of about 500 millimeter from this first pressure transducer and this location is about 1035 millimeter from this end flange.

So, if you take our reference as the end flange, the second pressure transducer is 1335 millimeter and the first pressure transducer is 1885 millimeter. So, now let us see the sequence of events that happens. So, in the driven section the shock wave first propagates the towards the end flange and followed by the shock wave there is induced mass which is at a elevated pressure. And, this elevated pressure we are going to measure through this pressure transducers.

Now, typical pressure transducer as I can show you; this is a piezoelectric type pressure transducer. So, you can see this is very simple system is a pressure transducer which has a sensing surface which is very flat. Now, when it is mounted like this, so, we are going to see the static pressure because it is mounted towards the inner surface of this tube.

And, when the flow sees, this sensing surface response to this flow and since it is a piezoelectric type there is a diaphragm that vibrates and subsequently through this oscilloscopes which is shown here we are going to tap the pressure jump across the shock wave. Now, the instrumentation part for this pressure transducer here is that this pressure transducer has to be connected to a power supply unit because this sensor has to be powered by the power supply unit and from there the output from that is going to take in the oscilloscope.

So, this is how the pressure transducer instrumentation with respect to oscilloscope is concerned. We are going to take the final measurement of pressure jump across the shock wave using this oscilloscope. The other important part of this pressure transducer is that when the shock wave travels in the driven section; the first pressure transducer sees it first. So, it will respond immediately, but by that time the second pressure transducer has not seen it so, it will not show any signal.

So, when the first pressure transducer is triggered after certain time, the second pressure transducer gets triggered. And, since from this oscilloscope signal we can record that how much time does the induced mass takes to travel from first pressure transducer location to the second pressure transducer location.

So, in this process we know the time from this pressure signal and we also know the distance between this pressure transducers. So, this distance and this time from this oscilloscope will give you the shock speed. So, in this way we can get the shock speed and subsequently knowing the speed of sound we can calculate also the shock wave mach number.

So, the pressure transducer does the two purposes – one is that it records the time which gives the shock Mach number, at the same time it also gives the pressure jump across the shock wave. Now we have said that the shock wave now cross the first pressure transducer, second pressure transducer and we recorded this signal.

Subsequently, the shock wave will travel and finally, there is end flange; that means, this is the end portion of the shock tube. And, this is the end flange; it is a kind of a end portion of the tube for which the inner surface is flat and the shock wave is trying to reflect.

Now, when we are looking at the reflected shock wave, means that already the induced mass motion has gained the pressure jump of the primary shocks. So, when the shock wave gets reflected from the end flange it sees the mass which is already at elevated pressure. So, when again the reflected shockwave travels back or in the opposite direction of this shock tube, then the second pressure transducer sees the reflected shock pressure and subsequently it is seen by the first pressure transducer.

Now, in this environment already the medium is pre elevated due to the primary shock. And finally when we see the pressure jump in the oscilloscope we can see there will be another pressure jump in the oscilloscope; so, which says that the reflected pressure is much higher than the primary shockwave pressure.

So, all these things we are now going to demonstrate by conducting a simple experiment and these experiments will tell you how the pressure jump is recorded instantly in the oscilloscope.

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So, we are going to show now that how a diaphragm looks like before before its rupture and after its rupture. So, what we see here is the first diaphragm and for this first diaphragm this diaphragm is connected between driver and driven sections at the beginning of the experiments.

So, as you can see there is a V groove and after the rupture if we are able to capture the shock wave means that all the compression waves merge and the rupture is initiated at this center point, then the photograph of this after the rupture can be seen in this fashion. So, it means that this is a flower like petals and it ruptures from the centre point all the four portion or four leaves have a unique and uniform ruptures as you can see from this photograph.

Now, if at all the rupture is not initiated by shock wave then what you can see an erratic fashion of a rupture locations some are like petals, some are like bent. So, as you can say that this rupture is not due to the shock wave rather it can be only due to the compression waves that means in this situation we can be sure that it is not due to the shock wave rather due to compression waves.

Now, this is the pressure transducer which is mounted in the driven section of the shock tube. This is the sensing surface which sees the flow and this pressure transducer is a model of 113B22 and this is made out of PCB Piezotronics and this particular pressure transducer is located at the driven end of the shock tubes. Now, we will move on the instrumentation for this pressure transducer and this instrumentation is mainly power supply cum signal conditioner and the oscilloscope or the data acquisitions.

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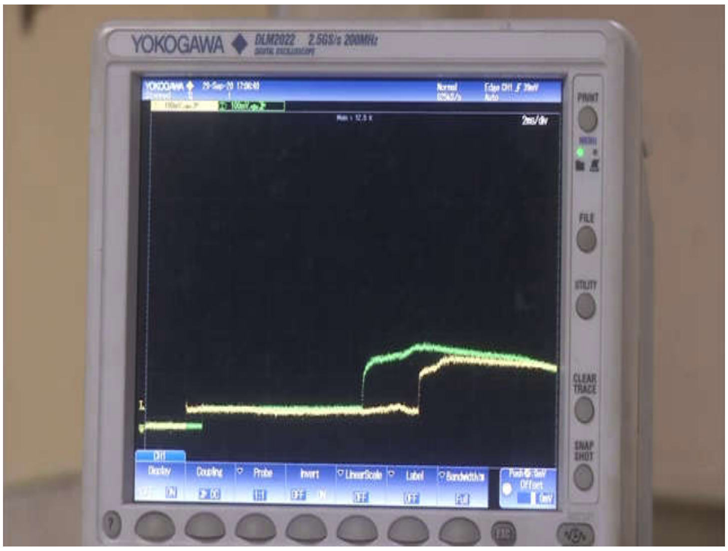

So, let us see that what are the instrumentation for the pressure transducer and how you are going to acquire the primary shock pressure jump and the secondary or reflected shock pressure jump using these oscilloscopes. So, for that purpose I have shown you the PCB pressure transducer. The connecting wires from the PCB transducers which is mounted from the driven sections of the tube, it is connected to a power supply unit which is also made by PCB Piezotronics.

This power supply unit has a unique feature that it supplies power to the pressure transducer as well as it also suppresses the unwanted signal and we call this as a noise. So, we call this as a signal conditioner. So, side by side it also conditions the signal as per the requirement.

And, second thing for the data acquisition part; as you can see the data acquisition part in the shock tube experiment is a very simple instrument which is the nothing but oscilloscope. So, basically the oscilloscope captures the voltage time data from the pressure transducers.

So, the main unique feature for this oscilloscope is that it is a Yokogawa model and its sampling rate is about 200 MHz or 2.5 Giga samples/s. So, that means, we can take samples of .5 Giga samples/s data in these oscilloscopes. So, it means that the short duration timely events can be taken and all those data are recorded in voltage and time format.

So, in the oscilloscope the x-axis refers to time axis and this y-axis refers to the voltage axis and in our experiment our y axis is nothing but the pressure transducers. So, as you see there are two colors of reference line because we have not started the experiments. So, these two colors refers to each of the pressure transducers. So, that means, this shows that two pressures transducers are connected in this oscilloscope and this is at the reference line, we have not started the experiments.

Now, when we will do the experiments we will see that the pressure jump which is for the primary shock as well as for reflected shock will be shown as a jump in this reference line. So, now in the y-axis, we have a y-axis scale which we kept as 50 mV per division; that means, one division refers to 50 mV.

So, depending on how many divisions there is a rise and corresponding calibrated number of the pressure transducer as supplied by the company PCB, we can exactly map what pressure rise had caused that rise in the voltage signal. So, now, we are going to demonstrate an experiment which is going to be seen in this oscilloscope.

Now, we are going to demonstrate this shock tube experiments. So, before the start of the shock tube operation which means that filling the driver section pressure and vacuum pressure, one needs to do the all types of circuitry arrangement as far as the pressure transducer is concerned and the reference line for the data acquisition system. In this case we have this oscilloscope as you can see there are both reference lines for the pressure transducer green and the yellow, they are at the reference level.

Now, one thing we are going to emphasize here is that when you conduct the experiments we have to keep this oscilloscope in a auto mode; that means, we are allowing the scope to capture all the informations as set within this scope. So, for that we need to fix a trigger lines. So, trigger line means it is a kind of another voltage which you are going to set. So, this line we can set it means that any value above this it should capture.

So, currently as a first guess one may show that in order to capture all the events that happen for the shock tube, I am setting a particular value in the voltage scales. And, from our experience it goes that if you set voltage scale of about 39 – 40 mV, then all the informations can be captured. So, as you see that we have set this trigger line at this locations and these are the reference line.

Now, I am switching on this instruments which means if I said that the oscilloscope is waiting for the data to come for its recording. So, here which I am switching on so that means, we are setting this oscilloscope to capture the data. So, in this process we are now going to pressurize the driver sections and at particular instance the diaphragm is going to rupture. The entire sequence of event starts and both the pressure transducer is going to record its signal in the form of voltage and time in this oscilloscope.

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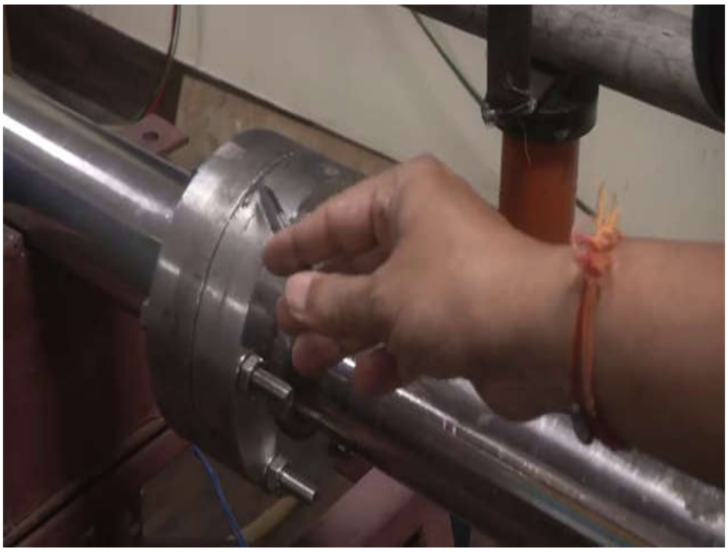

So, as you see that to have inserted a diaphragm at this interface location between driver section and driven sections, and this pressure of the driver section we are going to record in a pressure gauge.

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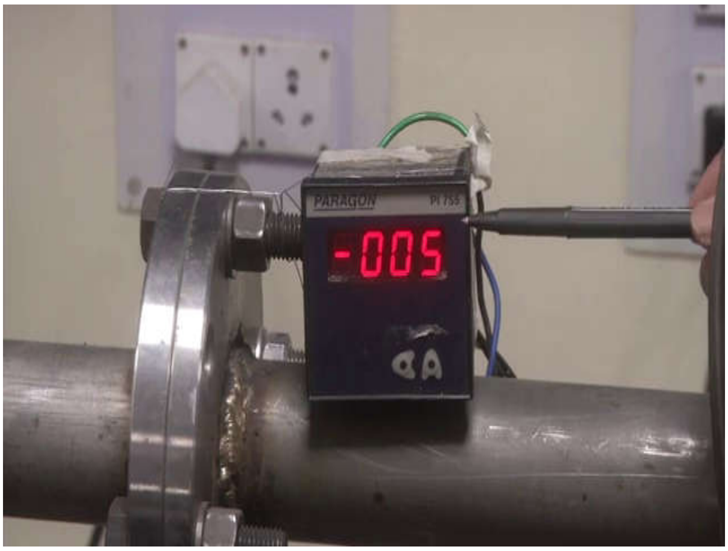

So, for this pressure gauge you can see there is a reference line which is almost 0, but; however, this is the instrument bias error, there is a marginal error. However, we can put this as a reference line which is seen that there is a almost the pressure or what you say with respect to this value is 0.

Now, we are going to pressurize in the driver section and pressure recording data from this pressure gauge we can see how the pressure is going build up in the driver section. So, here you see that pressure keeps on increasing and this pressure is being recorded with respect to psi and pressure is now 129, 141, 150, 156, 165, 183, 200 psi, 218 psi, 235 psi.

So, you can see that at 262 psi it ruptures and finally, after this rupture pressure value comes down and this pressure is finally steady state pressure. Once the both driver section gas and driven gas they mix up from the ultimate pressure which is at the end of the experiment in the tube is 85. Since we have not exhausted the gas from this shock tube, the final steady state pressure now turns out to be around 83 psi.

Now, if I remove this pressure valve you can see that this pressure come down further; that means, we are leaking this gas out of the shock tube and finally, we are bringing back this pressure level to this reference line. So, this is how the pressure gauge connected to the driver section of the shock tube records the rupture pressure of the diaphragm.

So, as you see from the scope instantaneously both the reference line shoots off. So, you see there are two signals which is captured in this oscilloscopes. The yellow line refers to the first pressure transducer which is located at 1885 millimeter from this end flange and the second pressure transducer is located 1335 millimeter from the end flange.

That means, when the shock wave travels in the driven section of the tube; the first pressure transducer sees the flow information of the induced mass and this jump if you can see it is instantaneous it is like a step. So, this instantaneous jump refers to the primary shock generations. Now, subsequently till that point of time you can see that green line which is in the pressure transducer 2 does not see the shockwave. So, it is shown as the same reference line.

Now, after that when the shock wave reaches to the location of the second pressure transducer, this also sees the primary shocks. So, for a certain duration in the time scale the entire value for the both the transducer remains same. So, this particular jump refers to the pressure jump after the primary shock.

Now, when you are coming to the second pressure transducer as you see that the reflected pressure jump is shown in another step rise of these signals. So, here the reference point is little bit reverse because the second pressure transducer sees the reflected shock first.

So, that is what it sees; the reflected shock first and this reflected shock keeps on rising and at this particular time it means that the entire induced mass has further rise in the pressure; that means, after this particular timescale the entire flow events is over and this means that it is the arrival of the contact surface followed by the driver gas. So, there is a sudden rise in the pressure as well.

Now, similar trend is also seen in the first pressure transducer. So, with respect to end flange the first pressure transducer shows this after a certain time delay and similar value of rise in the voltage signal is also observed. And, here if you see that by the time the flow has already been contaminated due to the arrival of the contact surface. So, you do not see any steady reason there is a continuous rise in pressures.

However, if you look at this particular timescale there is some kind of steadiness is seen whereas, in the first pressure transducer in the reflected event there is no steadiness is seen here. And, as I mentioned in the beginning that the arrival of the contact surface or other driver gases which are unwanted in our scenario this shows that further rise in the pressures.

But, at the outset what we are going to demonstrate in this event is that using the shock tube and using the pressure transducers, we are capturing the pressure jump across the primary shocks which is seen as the first jump for the pressure transducer 1 and also similar nature of the pressure jump at least across the reflected shock.

So, both the pressure transducer shows significant rise in the pressure jump across the shock wave. Now, looking at the y-axis timescale one can map that how much division it corresponds to. So, looking at the number of voltage divisions one can capture the pressure jump across the primary shock as well as reflected shock.

So, this is all about the end of this demonstration of the shock tube and as we have mentioned in the theory, more details can be found from the theory class. At the same time at the outset I can conclude this demonstration saying that a shock tube can be considered as a impulsive facility for generation of high speed slug of mass for a short duration time.

And, its main application as you can see here we have also attached a section which is used as a enclosure to study the deformation behavior for the metals and which is not part of this course.

So, at the end I will conclude this that shock tube is a simple laboratory one-dimensional tube, mainly intended for impulsive application measurements. And, these main application includes deformation behavior of materials, calibration of thermal sensors under step and impulsive response, then to some extent we can study the ignition delay of potential fuels.

So, these are the few applications of these impulsive facility and its utility is very vast as far as the high speed flow phenomena generation under impulsive domain is concerned.

Thank you.