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Research Article

Development Of Shock Tube For Shockwave Studıes

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Abstract

The present work is on designing, fabricating, and experimenting on shock tubes. Shock tube and processing system is a low-cost open-source alternative that has been developed and presented in this report. The use of available open-source hardware and software platforms like Arduino and pressure transducers was done.

A shock tube is a simple laboratory apparatus that can generate the various flow speeds at different flow regions and produce different types of Mach numbers. The Experimentation has been done with different thicknesses of aluminium diaphragms, producing the shockwaves with different Mach numbers. The shock tube performance is based on the wave's pressure ratio and speed in the driven section. Experiments were conducted in a circular cross-section shock tube with two sections: the driver section and another one is the driven section. Shock tube dimensions of 2.5m long with an inner diameter of 50mm and 2mm made of mild steel are used as experimental apparatus. The shockwave is generated by bursting thin diaphragms instantaneously with appropriate pressure ratios across the driver and driven section of the shock tube. The primary and reflected shock is measured by high-frequency pressure transducers located towards the driven section's end.

Keywords: *Shock tube, Shockwave, Mild steel, Diaphragm, Mach number*

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Introduction

In this project, we developed of small shock tube for shockwave studies, using Aluminum foil as Diaphragm

It is usually circular in cross-section and usually used metals like aluminum, mild steel, stainless steel, Polyvinylchloride, etc.

1.1 Shock tubes with an inert gas in the high-pressure chamber:

In this case, a driver gas is a hydrogen or helium at a pressure stretching from several to a hundred atmospheres and of initial ambient temperature. The shockwave velocity range from 0.5 to 6 km/s. The length of the high-pressure gas zone, depending on the tube length and the shockwave velocity.

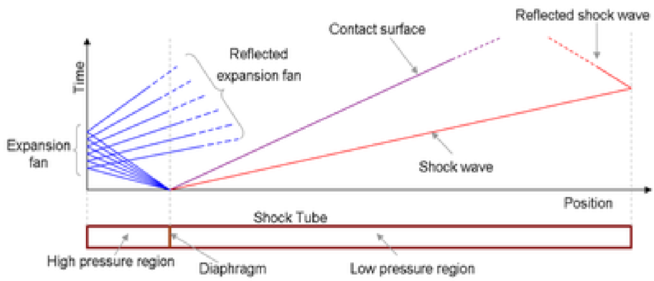

Figure. 1.1 Flow estimation of shock tube in High pressure and Low-pressure regions

1.2 Shock tube with shockwave enhancement:

In this category used for shockwave enhancement, the interaction of waves arising in the transition of a shockwave to sections with different pressure and cross-section. A shockwave in a shock tube flow factor behind the shockwave, such ad pressure, temperature, and velocity.

The shock tube is divided into two sections: one was the driver and another one driven section; in the driver, the section using high pressure to burst the Diaphragm, we use one pressure gauge in the driver section and two pressure transducers in the driven section.

In the driver section, we put an inlet on one end, and another end is open, and it is connected to the open end of the driven section; in the driven section, one end is closed, and another end is open, and it is attached to the open end of the driver section.

In between two open ends of two sections, we placed aluminum foil has Diaphragm. We are using Arduino software and Arduino Uno board for measuring pressure from pressure transducer and time.

Material Selection

Mild steel is a type of carbon steel with a low amount of carbon. It is essentially also known as low carbon steel. Mild steel is not alloy steel and does not contain large amounts of other elements besides iron. We cannot find vast amounts of chromium, molybdenum, or other alloying elements in mild steel. Since its carbon and alloying element content is relatively low, several properties differentiate it from higher carbon and alloy steels.

Less carbon means that mild steel is typically more ductile, Machinable, and wieldable than high carbon and other steels. The low carbon content also means it has very few carbon and other alloying elements to block disturbances in its crystal structure, usually resulting in less tensile strength than high carbon and alloy steels. Mild steel also has a high amount of iron and ferrite, making it magnetic.

- High tensile strength.
- High impact strength.
- Good ductility and weldability.
- A magnetic metal due to its ferrite content.
- Good malleability with cold-forming possibilities.
- Not suitable for heat treatment to improve properties.

Desıgn And Analysıs

CATIA V5R20 is used for designing the shock tube. It provides the design, simulation, and collaboration tools to deliver user needs for innovation.

ANSYS R20 software is used for analysing the various designs of the mounting structure. It is a complete FEA simulation software package developed by ANSYS Inc. – USA.

There are several analysis methods available in ANSYS software. We have selected Fluid Flow (Fluent) as it contains the board physical modelling capabilities needed to model flow, turbulence, heat transfer, and reactions for industrial applications ranging from flow over an aircraft wing to combustion in a furnace. Fluent (CFD) solver is established on the finite volume method. The steps contained in the CFD solver is

1) Pre-analysis
2) Geometry
3) Mesh
4) Physical Setup
5) Numerical Solution
6) Verification & Validation

This chapter deals with the design and analysis of shock tubes.

3.1 CHALLENGES IN DESIGN AND DEVELOPMENT

The design should have a minimum thickness, resist to high pressure, and reduced cost. These challenges are met while adhering to all regulatory requirements of safety, materials, processes, and production methods analysis.

3.2 LIFE OF STRUCTURE

Long life and minimum maintenance requirements are vital for a reduction in operating and maintenance costs while minimizing the overall life cycle cost. The life of the structure is increased by choice of materials and their properties.

3.3 DESIGN

In this phase, the detailed design of the shock tube is done. Component load is estimated, and material selection and sizing are made in this phase. The 3D model of the shock tube is done in catiaV520. All the lessons learned and practiced over the years are utilized in the detailed design to realize a reliable design. Various structural concepts have been considered, and it has enhanced for better and suitable structure for shock tube.

3.3.1 Model

Overall dimensions of our shock tube are:

- Total length- 2500mm
- Driver section length- 1000mm (high pressure region)
- Driven section length- 1500mm (low pressure region)
- Thickness – 2mm
- Diameter of each section- 50mm

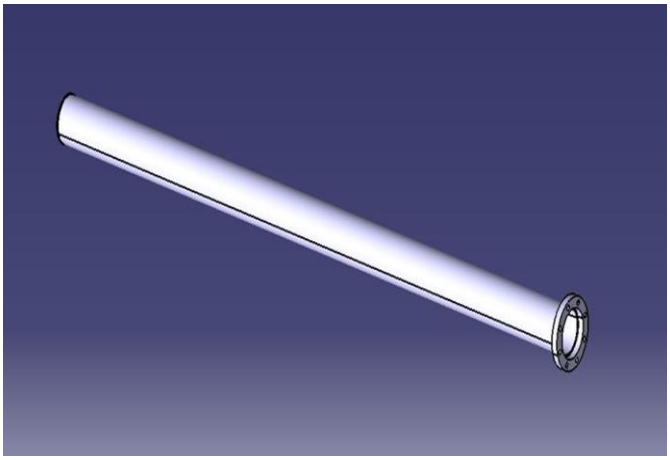

Figure. 3.1 Driver section Design done in Catia V5

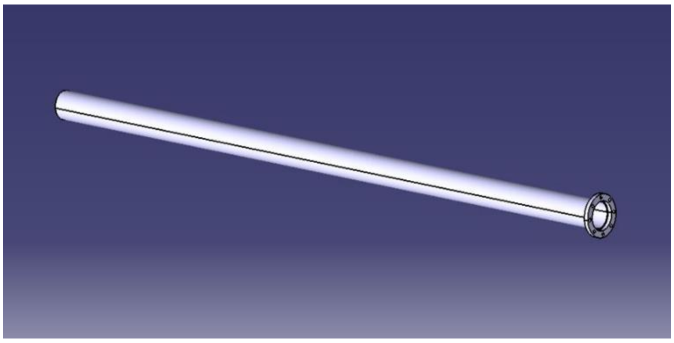

Figure. 3.2 Driven section Design done in Catia V5

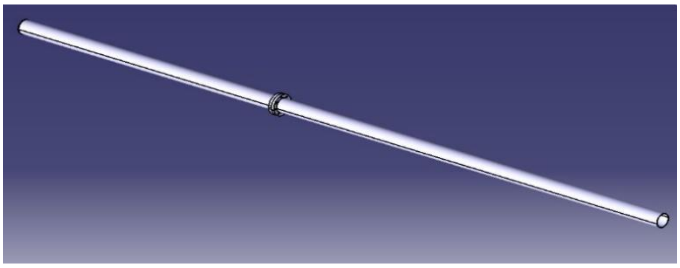

Figure. 3.3 Shock Tube Design done in Catia V5

Structural design is carried in CATIA V5R20 software using a circle, pad, reference plane, and pocket used in part design. In assembly design, we used existing components to import the two sections and assembled the two sections together.

3.3.2 ANALYSIS FOR DESIGN

For analysis, we used ANSYS R20 software. The following boundary conditions were considered:

- Driver section – High-pressure section(1000mm)
- Driven section – Low-pressure section(1500mm)
- For meshing
  - Face mapping is considered for all the faces
  - For edges, edge sizing for all the edges
  - And biasing is for top and bottom edge with a 6 factor
- A total number of nodes and elements:
  - Nodes – 505101
  - Elements – 500000
- A density-based solver is applied
- A steady timer is used
- The energy equation is ON.
- K-epsilon model is selected
- For cell zone conditions driver section is set to 101325pa.
- Boundary conditions are all set to zero.
- For initialization
  - Temperature(T)- 300K
  - Driver-300000, 500000, 700000pa
  - Driven-101325pa

3.3.2.1 ANALYSIS AT 7BAR

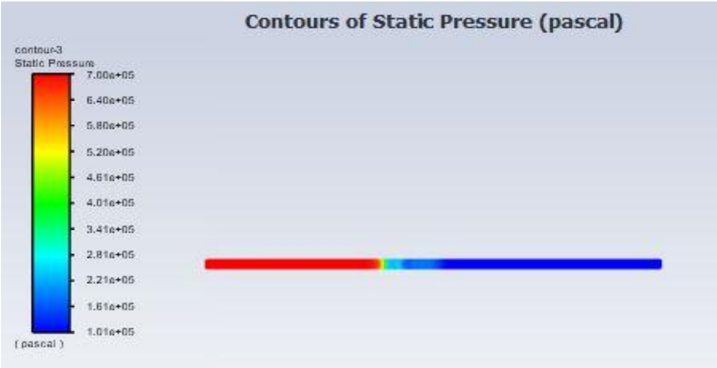

Figure. 3.4 Contours of Static Pressure at 7bar

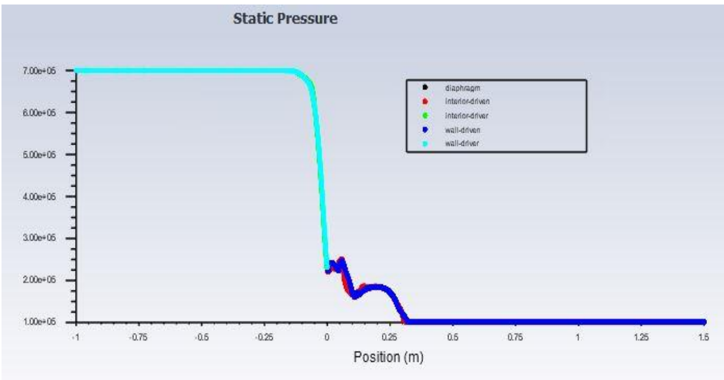

Figure. 3.5 Static pressure at 7bar

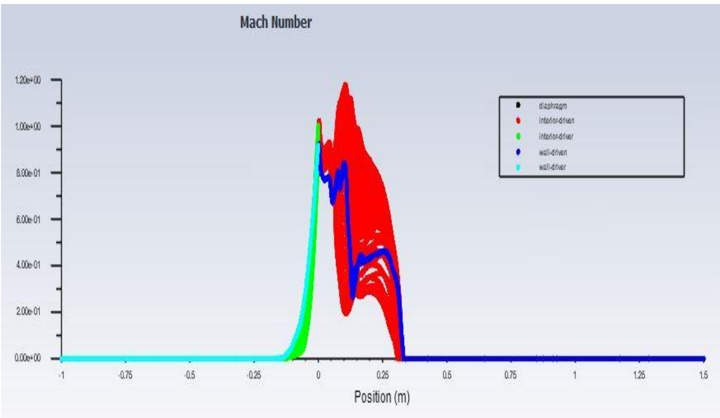

Figure. 3.6 Mach number at 7bar it can reach up to 1.2Mach

3.3.2.2 ANALYSIS AT 5BAR

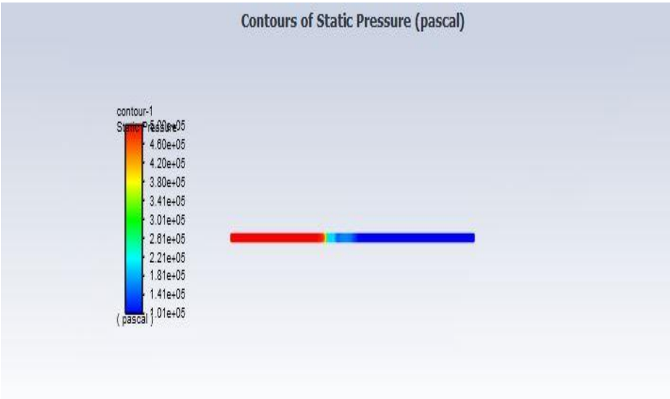

Figure. 3.7 Contours of Static Pressure at 5bar

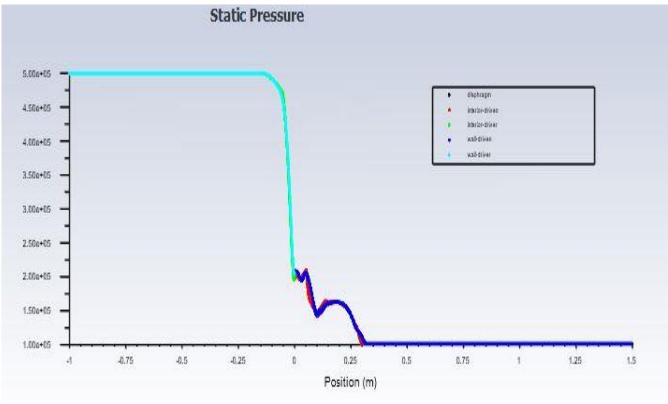

Figure. 3.8 Static Pressure at 5bar

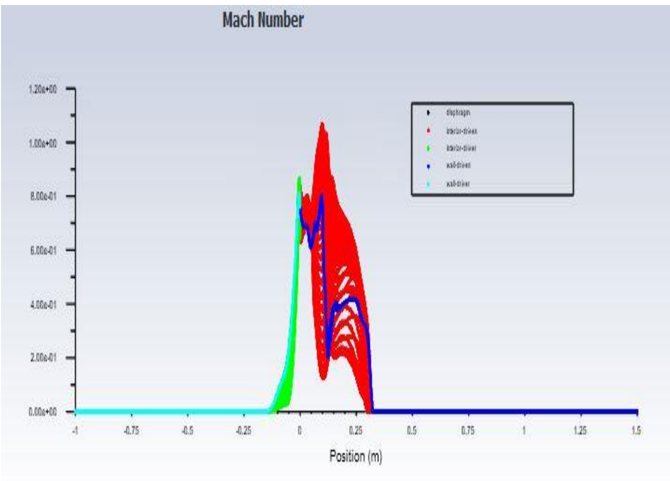

Figure. 3.9 Mach number at 5bar it can reach up to 1.2Mach

3.3.2.3 ANALYSIS AT 3BAR

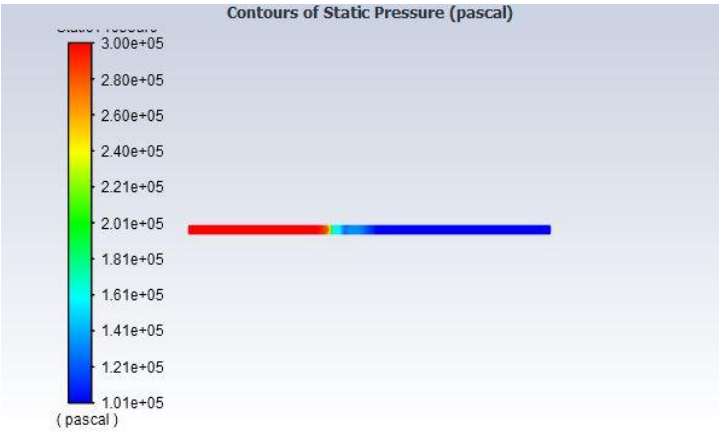

Figure.3.10 Contours of Static Pressure at 3bar

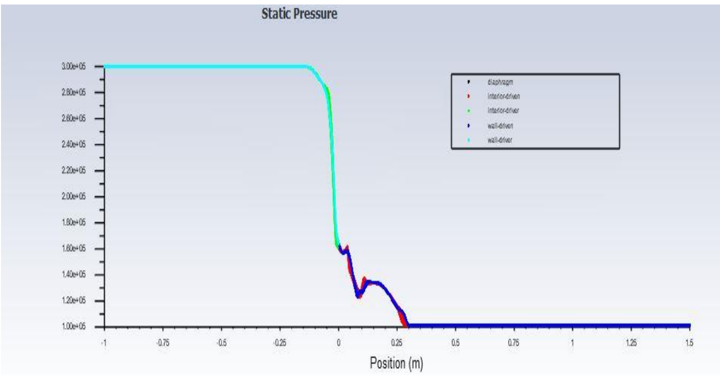

Figure. 3.11 Static Pressure at 3bar

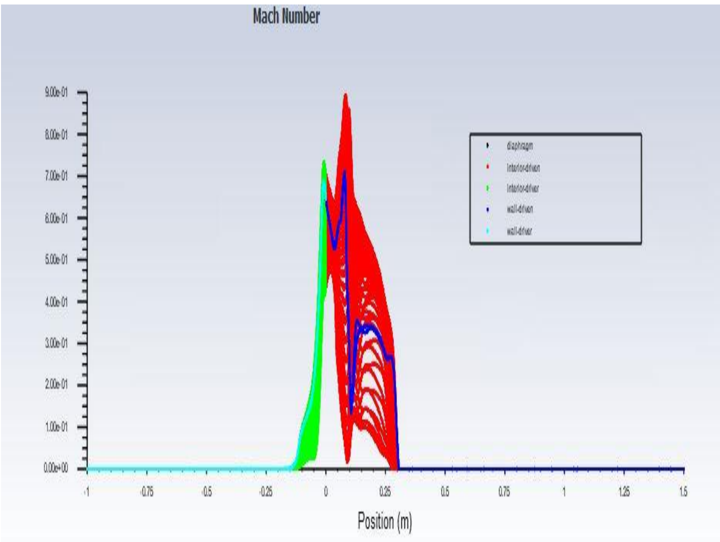

Figure. 3.12 Mach number at 3bar it can reach up to 0.9Mach

Software And Electronics

Arduino UNO is the best Board for programming and getting the results easily. We use the Arduino to get the results from the sensors. The Sensors we use are the pressure sensor to get the pressure build-up in the pipe and how it is traveling in the tube at two endpoints. The sensors calculate the initial pressure built in the tube and the blast after the tube's pressure. The sensor calculates the initial value that is calculated after the blast of the Diaphragm in the pressure sensor P1 and the pressure travels to the other end, the pressure sensor P2. The pressure sensor P1 and P2 will be a time difference in milliseconds calculated in the software. The reverse pressure is also calculated in the tube by using the sensors P1and P2. The reverse pressure is calculated by the time between the sensors P2and P1. The values are noted in the software in a digital form.

Figure. 4.1 Three view of Pressure transducer

Figure. 4.2 Pressure sensor and its positions at the either end of Driven section

The Arduino plays a vital role in collecting the data. Both sensors are connected to the Arduino board. The Arduino is connected to the laptop and the 12v Adapter. To run the sensors, a 12v Adapter is needed, the code in the laptop is uploaded to the Arduino board. The Board is the main part of collecting the data. With its analog pins connected to the sensors, the Board converts the sensor value to the digital readings with the help of code inside it. In the Arduino, there is a serial monitor and serial plotter, which helps to observe the values.

Figure. 4.3 Arduino board

4.1 CODE

sketch_mar23c | Arduino 1.8.13 (Windows Store 1.8.42.0)

File Edit Sketch Tools Help

sketch_mar23c

```
const int analogInpin=A0;
const int analogInpin1=A1;
int sensorValue=0;
int outputValue=0;
float p1,p2;
void setup() {
  //intialize serial communicationsat 9600bps:
  Serial.begin(9600);
}
void loop()
{
  sensorValue = analogRead(A0);
//outputValue = map(sensorValue,100,1023,0,146);
  Serial.print("P1:");
  //sensorValue=sensorValue-120;
  sensorValue=map(sensorValue,120,1023,0,146);
  Serial.println(sensorValue);
  delay(10);
  Serial.print("P2:");
  outputValue = analogRead(A1);
//outputValue = map(sensorValue,100,1023,0,146);
outputValue=map(outputValue,120,1023,0,146);
  Serial.println(outputValue);
  delay(10);
}
```

Figure. 4.4 Arduino code

Fabrıcatıon And Modellıng

The fabrication equipment used is the Cutting tool, Grinder tool, Drilling machine, Ark welding, Stand Drilling, Screwdriver, Pliers, Wrenches, etc.

Firstly, the selected material is Mild Steel from the above Material selection. The Mild Steel is taken as a pipe, and then Machining is done to remove the rough surfaces and get the smooth surface. Then the Mild Steel is cut into the possible dimension, so the experiment is done accordingly. Now we attached two Mild Steel Flange each for the pipe. The Flanges are welded at one end of the pipe so that the pipes can be attached or detached for use. The small section of the pipe is called the Driver section. The large section of pipe is called the Driven section.

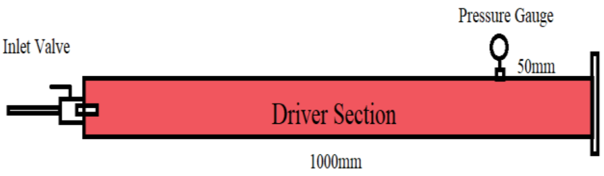

Figure: 5.1 Fabrication of Driver section

In the Driver section, the length is 1000mm shortest section, another end to Flange, and it is closed with the Mild Steel plate. In the plate, the center has drilled a hole with the driller, so the inlet valve is fixed to the plate and welded with the pipe. Near to the Flange, about 50mm a hole is drilled with the driller to attach the Mild Steel nipple so that we can fix the Pressure gauge. The pressure gauge is used to calculate the Driver section pressure before the blast of the Diaphragm.

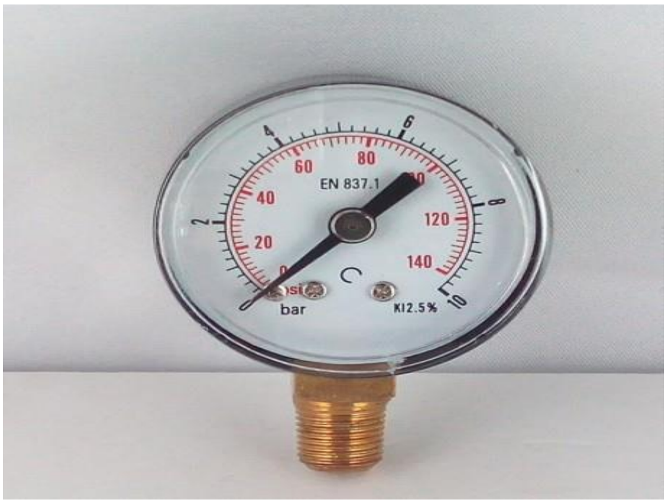

Figure: 6.2 Pressure gauge

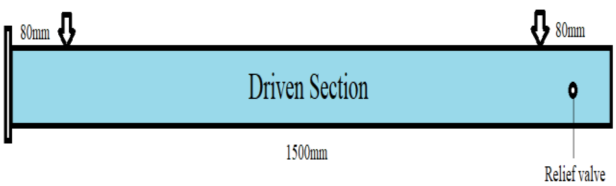

Figure: 5.3 Fabrication of Driven section

In the Driven Section, the length is 1500mm longest section, the other end to Flange, and it is Closed with the Mild Steel plate. In the Driven Section, one end is open, that is Flange, and the other end is Closed, with the plate. In the Driven section near the Flange, about 80mm, a hole is drilled with the driller to attach the mild steel nipple to connect the sensors. At the closed end near about 80mm, a hole is drilled with the driller to attach the mild steel nipple to connect another sensor. At the closed section near about 30mm, a hole is drilled with the driller to attach the relief valve to release the driver's air and drive section.

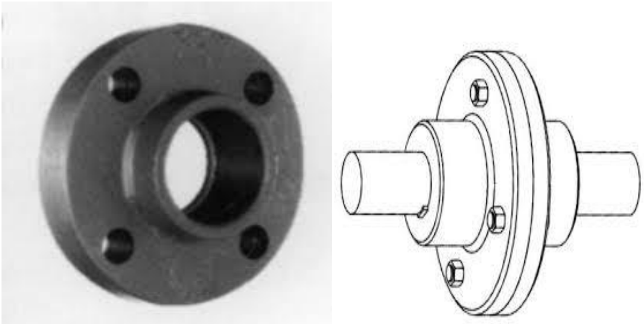

Figure. 5.4 Flange

To support the Driver and Driven Section, L-shaped steel is used to make the support. Moreover, to fix the sections, Clamps are used.

The Driver section's inlet at the drilled end ball valve is used to send and close the pressure inside the driver section. At the driven section near the closed end, the ball valve is used to send out the pressure inside the tube. The both Flange, in the middle, the rubber cork or the gasket is used to prevent the leaking of pressure. In the middle of the two gaskets, the Diaphragm is placed. At the welding areas, the metal sealant is used for the gaps in welding and for good sealant not to release the pressure out at the welded areas.

Figure. 5.5 Nipples and Ball valve

Experımentatıon And Observatıon

6.1 EXPERIMENTATION

The experiment is carried out by assembling all the parts together. The inlet ball valve is fixed and screwed tightly in the Driver section and sealed by using Teflon tape and, the pressure gauge is placed in the Driver section near the Flange. In the Driven section, the Pressure sensor P1 is fixed near the Flange and, the pressure sensor P2 is placed near the closed end of the Driven section. In-between the Flange of the Driver and Driven section, a rubber cork is placed to minimize the pressure leakage. In-between each rubber cork, the test is taken place. In the L-shaped stand, there are Four clamps are placed to fix the sections together. Now then fill the air in the compressor to start the test.

6.1.1 TEST 1 0.25MM

In this test 1, the material we use is 0.25mm thickness of Aluminium foil. The experiment is carried out by assembling all the parts together. In-between the rubber cork of the Flange, the test material is placed. Now release the valve at the compressor end. Now start running the Arduino code to take values. Now release the valve at the Driver section for one second; there, we will hear a popup sound, so the Diaphragm is busted. Now carefully loosen all the bolts and nuts near the Flange, remove the foil carefully and pick the fallen particles.

Figure. 6.1 Test 1 0.25mm thickness after a blast

6.1.2 TEST 2 0.50MM

In this test 2, the material we use is 0.50mm thickness of Aluminium foil. The experiment is carried out by assembling all the parts together. In-between the rubber cork of the Flange, the test material is placed. Now release the valve at the compressor end. Now start running the Arduino code to take values. Now release the valve at the Driver section for one second, there we will hear a popup sound, so the Diaphragm is busted. Now carefully loosen all the bolts and nuts near the Flange, remove the foil carefully and pick the fallen particles.

Figure. 6.2 Test 2 0.55mm thickness after a blast

6.1.3 TEST 3 0.75MM

In this test 3, the material we use is 0.75mm thickness of Aluminium foil. The experiment is carried out by assembling all the parts together. In-between the rubber cork of the Flange, the test material is placed. Now release the valve at the compressor end. Now start running the Arduino code to take values. Now release the valve at the Driver section for one second, there we will hear a popup sound, so the Diaphragm is busted. Now carefully loosen all the bolts and nuts near the Flange, remove the foil carefully and pick the fallen particles.

Figure. 6.3 Test 3 0.75mm thickness after a blast

6.2 OBSERVATION

We observed the pressure readings in the inlet Driver section and the Pressure sensor readings from Arduino monitor readings. In the Arduino readings, each reading is taken to calculate the time between the two pressure sensor readings. For each test, each observation is taken.

6.2.1 TEST 1 0.25MM

- The Inlet Pressure at the Driver section in Psi = 58
- Time taken for the initial shockwave = 0.0046 (0.0525-0.0571)

- Time taken for the reflected shockwave seconds(R) = 0.0045 (0.0618-0.0663)
- Distance between the two pressure sensors = 1484mm
- Mach no for the initial shockwave = 0.94
- Mach no for the reflected shockwave = 0.96
- Pressure sensor readings for initial shockwave P1 = 50psi
- Pressure sensor readings for initial shockwave P2 = 53psi
- Pressure sensor readings for reflected shockwave P1* = 52psi
- Pressure sensor readings for reflected shockwave P2* = 54psi

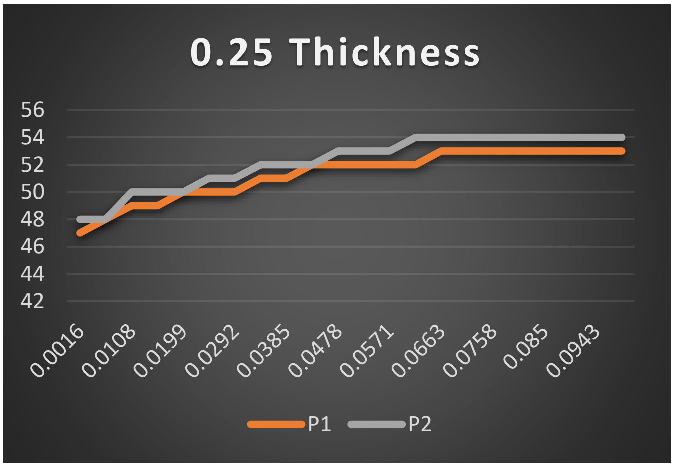

Figure. 6.4 Pressure Vs Time at 0.25mm thickness

6.2.2 TEST 2 0.50MM

- The Inlet Pressure at the Driver section in Psi = 58
- Time taken for the initial shockwave = 0.0047 (0.0502-0.0549)
- Time taken for the reflected shockwave seconds(R) = 0.0046 (0.0549-0.0641)
- Distance between the two pressure sensors = 1484mm
- Mach no for the initial shockwave = 0.92
- Mach no for the reflected shockwave = 0.94
- Pressure sensor readings for initial shockwave P1 = 45psi
- Pressure sensor readings for initial shockwave P2 = 47psi
- Pressure sensor readings for reflected shockwave P1* = 47psi
- Pressure sensor readings for reflected shockwave P2* = 48psi

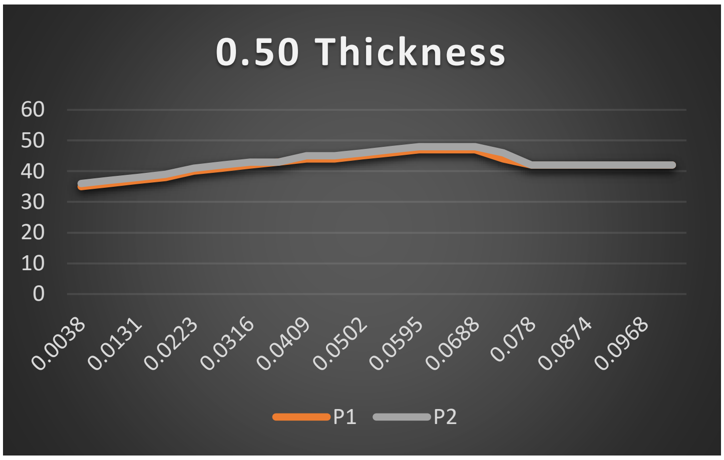

Figure. 6.5 Pressure Vs Time at 0.50mm thickness

6.2.3 TEST 3 0.75MM

- The Inlet Pressure at the Driver section in Psi = 66
- Time taken for the initial shockwave = 0.0046 (0.0121-0.0167)
- Time taken for the reflected shockwave seconds(R) = 0.0047 (0.0213-0.0260)
- Distance between the two pressure sensors = 1484mm
- Mach no for the initial shockwave = 0.94
- Mach no for the reflected shockwave = 0.92
- Pressure sensor readings for initial shockwave P1 = 51psi
- Pressure sensor readings for initial shockwave P2 = 54psi
- Pressure sensor readings for reflected shockwave P1* = 55psi
- Pressure sensor readings for reflected shockwave P2* = 56psi

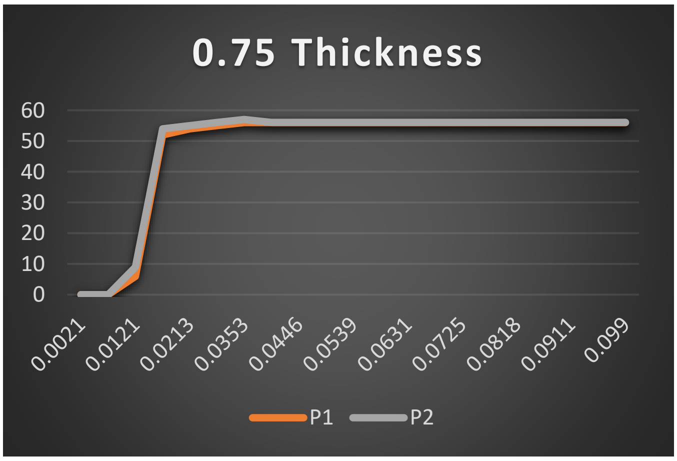

Figure. 6.6 Pressure Vs Time at 0.75mm thickness

6.2.4 COMPARISION OF INITIAL Vs REFLECTED SHOCKWAVE

The graph shows the difference of Initial Vs. Reflected Shockwave.

Thickness	Initial	Reflected
0.25	0.94	0.96
0.50	0.92	0.94
0.75	0.94	0.94

Table. 6.1 Initial Vs Reflected

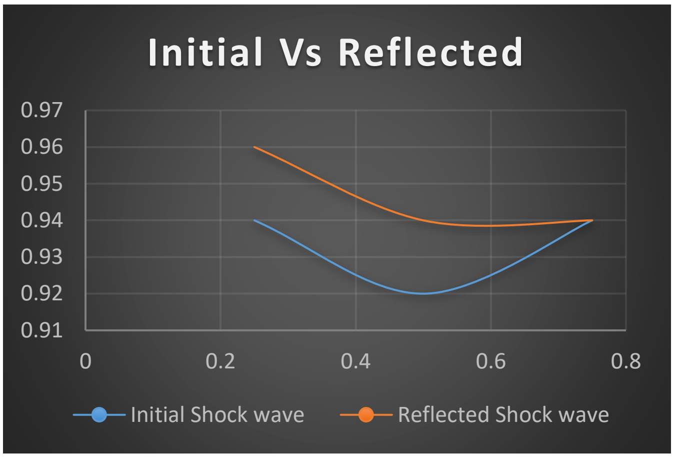

Figure. 6.7 Initial Vs. Reflected shockwave

6.2.5 COMPARISION OF EXPERIMENTAL Vs THEORETICAL

The Experimental Vs Theoretical graphics has been plotted based on the Mach numbers. The graph plotted on the initial shockwave and the Reflected shockwave.

Initial Shockwave

P2/P1	Theoretical	Experimental
3.57	1.8	0.94
3.21	1.7	0.92
3.64	1.8	0.94

Table. 6.2 Initial Shockwave

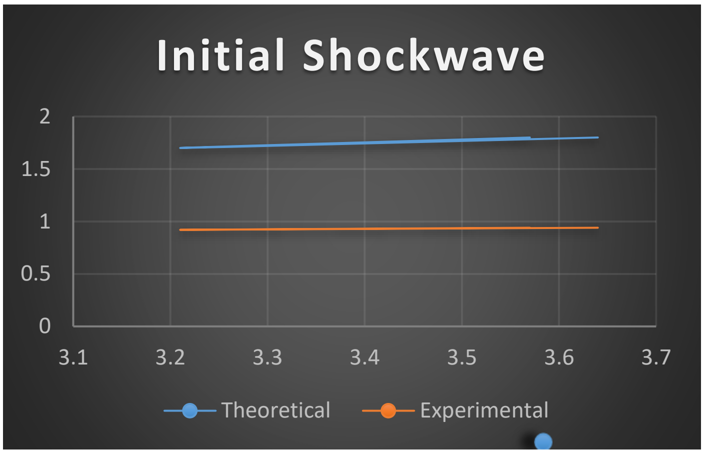

Figure. 6.8 Initial shockwave

P5/P1	Theoretical	Experimental
3.85	1.3	0.96
3.42	1.3	0.94
4	1.4	0.94

Table. 6.3 Reflected Shockwave

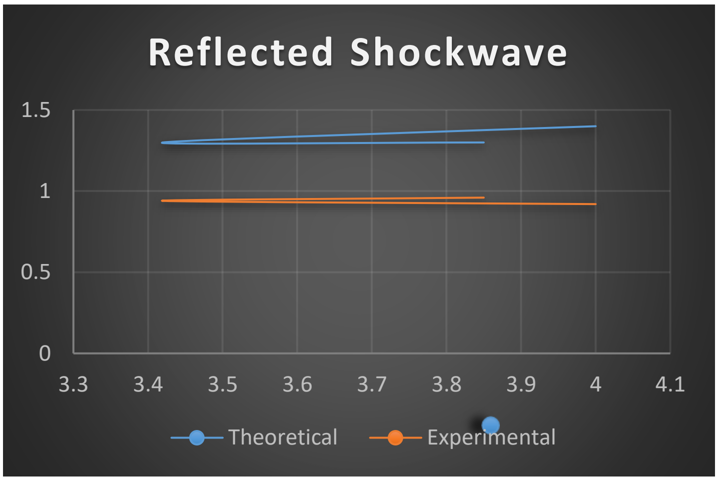

Figure. 6.9 Reflected Shockwave

Conclusion

A shock tube is successfully designed, fabricated, and calibrated, and it effectively works for shock wave studies. In the first phase, we design a shock tube in Catia software, and shock flow physics is earned through CFD simulations. An experimental setup is considered for measurement experiments on a spherical model equipped with a pressure gauge and pressure transducers and using freely available open-source hardware and software. The processor is a 5.3MHz speed, Arduino Uno, with an Atmega328P microcontroller capable of sensing supersonic speed movements. In this experiment, the response time of pressure transducers and note down pressure in the serial monitor of Arduino software, the tests performed within the 6bar pressure. Aluminium foils of different layers taken as a Diaphragm, based on the driver section's pressure, the Aluminium bursts and produces the Mach. We conclude that based on the results from Theoretical and Experimental, the Shockwave formed is Higher in Theoretical and Lower in Experimental. The reason behind the difference is not based on the surface and length of the shock tube in the Theoretical.

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