The shock tube is a device in which a normal shock wave is produced by the sudden interaction of separating fluids at significant pressure difference. When the interaction happens, a shock wave forms almost instantaneously and propagates, while simultaneously an expansion wave propagates in the opposite direction.The most commonly used technique to set such initial conditions is the use of a bursting diaphragm; however a high speed valve provides better control over such an event. In this particular case, a high speed valve is used for the generation of the shock wave. In this setup, solenoid valves are placed at various locations to control the filling and safe operation of shock tube. The shock tube is fitted with three pressure sensors. The particular setup has a computerized data acquisition system. The operation of shock tube and its various sensors are programmed to auto trigger to gather the data of the event. This report discusses the details of the shock tube experimental facility.

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Shock Tube Experimental Setup

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# Shock Tube

## Detail overview of equipment and instruments in the shock tube experimental setup

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## Abstract

The shock tube is a device in which a normal shock wave is produced by the interaction of fluids at significantly high-pressure difference. The shock tube is comprised of two sections known as driver and driven sections. These two sections are interacted with the high-speed valve or a bursting disc. When the interaction happens, a shock wave forms almost instantaneously and propagates into the driven section, while simultaneously an expansion wave propagates in the opposite direction into the driver section. The most commonly used technique to set-up such initial conditions is the use of a bursting diaphragm; however, a high-speed valve provides better control over the event.

In the given setup, a high-speed valve is used for the generation of the shock wave. In this setup, solenoid valves are placed at various locations to control the filling and the safe operation. The shock tube is fitted with three pressure sensors. First pressure sensor is placed in the driver section whereas two other pressure sensors are placed in the driven section. A T-joint is placed in the driven section to mount a specimen for the study. The particular setup has computerized data acquisition system, which can record information up to 1MHz. The operation of the shock tube and its various sensors is programmed to auto-trigger to gather the information.

Hassan Abbas Khawaja
Juma Kapaya
Mojtaba Moatamedi

# Table of Contents

## Nomenclature

Abbreviations:

| | |
|---|---|
| Eng. | Engineer |
| SOPs | Standard Operating Procedures |
| $R_G$ | Gauge resistance |
| $\Delta R$ | Change in resistance |
| GF | Gauge factor |
| $\varepsilon$ | Strain ratio |
| $\Delta L$ | Change in length |
| Ni | Nickel |
| Cu | Copper |
| Fe | Iron |
| Mo | Molybdenum |
| $^0F$ | Degree in Fahrenheit |
| $^0C$ | Degree in Centigrade |
| LV-Source code | LabVIEW-Source code |
| VI/Vis | Virtual Instrument |
| DAQ | Data Acquisition |
| I/O | Input/output |
| A/D | Analogue-to-Digital |
| PC | Personal Computer |
| NI | National Instrument |
| API | Application Program Interface |
| RTDs | Resistance Temperature Detectors |
| TTL | Transistor-to-Transistor Logic |
| SNR | Signal-to-Noise Ratio |
| ADC | Analogue-to-Digital Convertor |
| AIGND | Analogue Input Ground |
| UK | United Kingdom |
| FP | Flexible Pipe |
| V | Valve |
| SV | Safety Valve |
| CNG | Compressed Natural Gas |
| P | Pressure Gauge |

| | |
|---|---|
| KHZ | Kilohertz |
| Pf | Peta farad |
| mA | Milli Ampere |
| DC | Direct Current |
| Pa | Pascal |
| OSHA | Occupational Safety and Health Administration |
| PPE | Personal Protective Equipment |
| MSDSs | Material Safety Data Sheet |
| NFPA | National Fire Protection Association |
| AC | Alternating Current |
| AI | Analogy Input |
| AO | Analogy Output |
| Ms | milliseconds |
| AC2DC | AC to DC |

# Chapter 1: Introduction

## 1.1 General

The shock tube is a device in which a normal shock wave is produced by the interaction of fluids at significantly high pressure difference. The shock tube is comprised of two sections known as driver and driven sections. These two sections are interacted with the high-speed opening valve or a bursting disc. When the interaction happens, a shock wave forms almost instantaneously and propagates into the driven section, while simultaneously an expansion wave propagates in the opposite direction into the driver section [1].

The shock and expansion waves are generated when the fluids at high and low pressures are in contact [1]. The common technique used to set-up such initial conditions is the use of a bursting diaphragm, however, high-speed valve provides better control over the event of shock wave generation and initial pressure value [1]. In this work, high-speed valve is used for the generation of the shock wave [1]. In this setup solenoid valves are placed at various locations to control the filling and safe operation of the shock tube experimental setup. The shock tube is fitted with three pressure sensors. The first pressure sensor is placed in the driver section whereas two pressure sensors are placed in the driven section [1]. A T-joint is placed in the driven section to study the materials under the influence of shock wave impact [1]. This particular setup has a computerised data acquisition system which can gather information up to $10^6$ Hz. The operation of the shock tube and its various sensors is programmed to auto-trigger to record the data [1].

This particular experimental facility is useful to study the normal shock and expansion waves in the fluids. With slight modification, it can also be used for study of fluid jets, cavitation, and other physical phenomenon in fluids.

## 1.2 Purpose

The shock wave tube testing facility is useful for wide range of investigations, for example, testing the use of new lightweight materials under dynamic loading for its use in engineering applications [2, 3].

The purpose of this report is to show the reader how to collect the information from the shock tube experimental setup. This report gives the descriptions of specifications for the equipment used in setting-up the shock wave tube. It discusses safety, limitations, risk assessment, and standard operation procedures (SOPs). The report includes figures and drawings to explain the setup.

## 1.3 Working principle of shock tube

Shock tubes operate by using difference in fluids pressures to create a shock wave. This is achieved by creating two sections of the shock tube, one with high pressure (also known as the driver section) and other with low pressure (also known as driven section). A thin piece of metal or plastic called a diaphragm is placed in-between to separate two sections [4]. Driver section is charged with high pressure fluid (air is used in this case). As the pressure builds in the driver section, more stress is built on the diaphragm. It keep building pressure until it bursts. The driver section pressure is controlled by the strength of the bursting plate (using thickness and type of material). After the burst, a shock wave flows down the low pressure end of the tube called the driven section while an expansion wave flows down the high pressure end of the tube known as the driven section. These waves equalize the pressure in the tube [5]. A layout of a shock tube is given in figure 1-1.

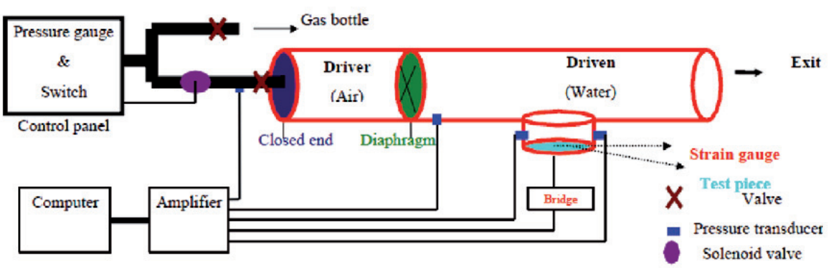



Figure 1-1: Layout of a Shock Tube

Figure 1-2: Shows the various bursts of diaphragms

## 1.4 Brief history of shock tube

Paul Vieile used the first shock tube in France in 1899 [4]. Shock tubes did not come into general use until the blast wave studies during World War II [5]. Since then, shock tubes have been used to develop the laws of reflection for shock and expansion waves, shock wave diffraction, gas dynamics at high temperatures, study of detonations, and act as high-speed wind tunnels for supersonic and hypersonic flows. Earlier shock tubes were installed with state of the art instrumentations and high-speed data acquisition systems, however the cost was very high and performance was very low in comparison to the modern systems [4, 5].

## 1.5 Overview of the report

This report consists of five chapters:

- First chapter gives a brief overview of the shock tube.
- Second chapter describes specifications of the equipment in the shock tube.
- Third chapter covers safety, limitation of usage, and risk assessment in the operation of shock tube.
- Fourth chapter covers the standard operating procedures (SOPs) of the shock tube.
- Fifth chapter is the conclusion and the future work.
- Appendices contains specifications of the equipment and safety certifications.

# Chapter 2: Equipment in Shock Tube Testing Facility

## 2.1 Introduction

The shock tube system consists of variety of equipment. These are connected together to make a setup. The names of the equipment are listed in Appendix A1.

## 2.2 Specification of the Equipment

In the shock tube experimental facility, equipment with the required specifications are put together according to the design specifications [1]. Specifications for the various equipment items are given in this chapter.

### 2.2.1 Compressed air cylinder

A compressed air cylinder is the source of pressurised air in the shock tube. It has capacity of 300 bar, volume of 50 litres and weight of 74.4 kg. It is fitted with a manual valve (V1) and flexible hose tube (FP1) (see figure 2-1). The cylinder meets the required standards for industrial usage (Appendix- B3).


Figure 2-1: Compressed air cylinder with valve and flexible pipe

Cylinder valve V1

A knob operates the cylinder valve. Clockwise turning of the knob opens and anticlockwise closes the valve. The valve is attached to the neck of the cylinder by screw threads as shown in figure 2-2.

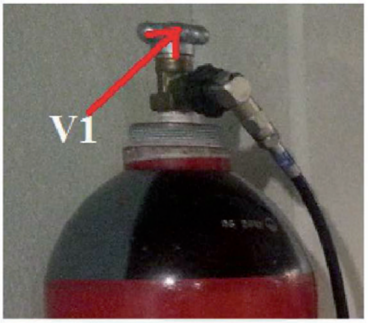



Figure 2-2: Cylinder valve

Flexible hosepipe (FP)

The flexible hosepipe is used to connect the high-pressure cylinder with the control panel (See figure 2-3). This hosepipe is 1275 mm in length and made of various materials laminated together to provide sufficient strength for high-pressure usage. The flexible hose is bolted at both ends.

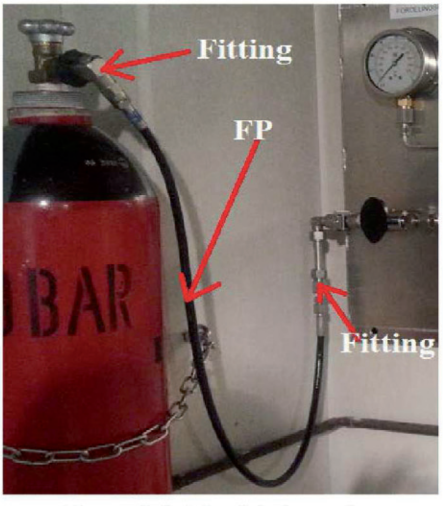



Figure 2-3: Flexible hosepipe

### 2.2.2 Control Panels

There are two control panels in the shock tube testing facility, namely: main control panel and remote control panel. The main control panel is the one that is located inside the room of the shock tube. This control panel consists manual valves, pressure gauges, safety valves, pressure-reducing valve, solenoid valve for remote operation and static pressure sensor (See figure 2-4). The remote control panel consists of various switches, a data acquisition system, a Wheatstone bridge circuit (for strain measurement), a block terminal and a personal computer, see Appendix A2. The remote control panel will be discussed later.

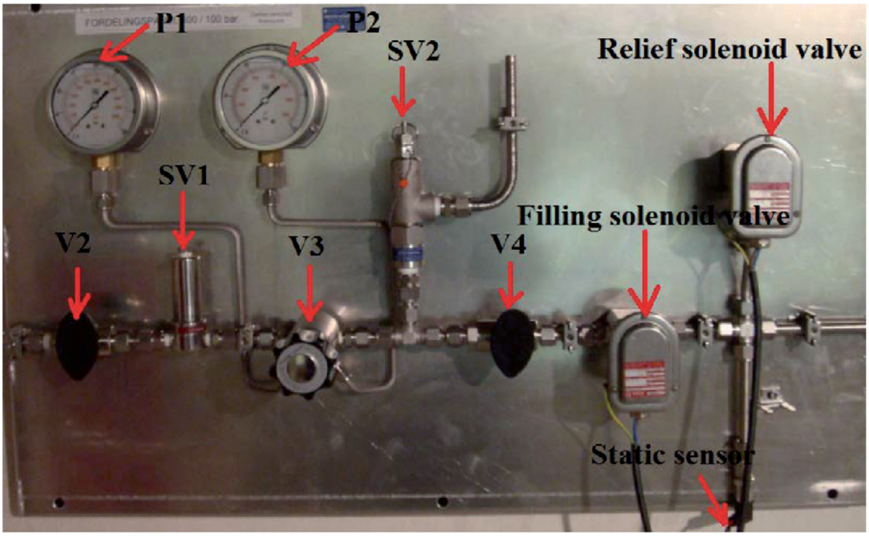



Figure 2-4: Main control panel

#### Valves

In the main control panel, there are three main groups of valves, these are manually operated valves (V2, V3 and V4), electrically operated valves (Filling and relief solenoid valves) and the third group of the valves were safety relief valves (SV1 and SV2), see figure 2-4.

#### Manually Operated Valves (V2, V3 and V4)

As shown in figure 2- 4 and in the Appendix A2, valves V2, V3 and V4 are manually operated valves. These valves are described below.

**Manually Operated Ball Valves (V2 and V4):**

These are S Series, sandwich style, ball valves can be operated up to 6000 psi (413 bar). They are manufactured with the choice of threaded and socket or butt weld ends for easily installation into the pipeline. They are constructed by 316 S11 stainless steel threaded with NPT, BSPP and BSPT. Once these types of valves are installed, they are easily maintained by removing the centre section for renewing the seats and seals to prolong the valves life.

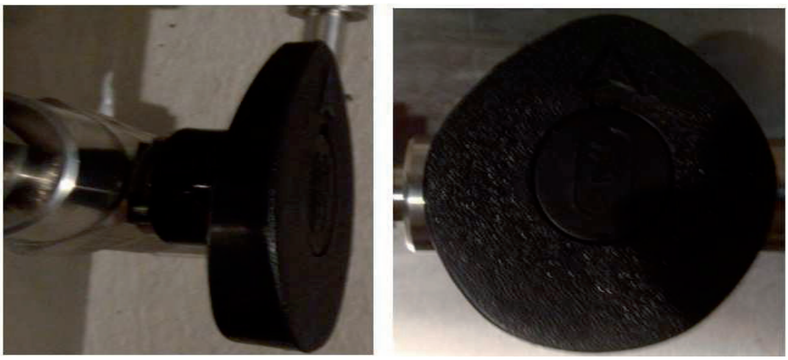


Figure 2-5: Shows Manual valve (V2 and V4)

**Pressure Reducing Valve (V3)**

The function of the pressure reducing valve (see figure 2-6) is to precisely reduce a high upstream pressure to a lower, suitable pressure for the user's application. Furthermore, the regulator is used to maintain and control the outlet pressure within limits. This valve does not regulate flow rate. The regulator consists of load mechanism, sensing element and control element, see figure 2-6.

This valve has maximum rated inlet pressure of 6000 psi (413 bar), design outlet proof pressure 150% of maximum rated pressure, operating temperature rated between -40$^0$C to +74$^0$C and maximum operating torque of 1 Nm. The body and bonnet are constructed of 316 and 300 stainless steel respectively. The connection has ¼" NPT inlet, outlet and gauge ports.

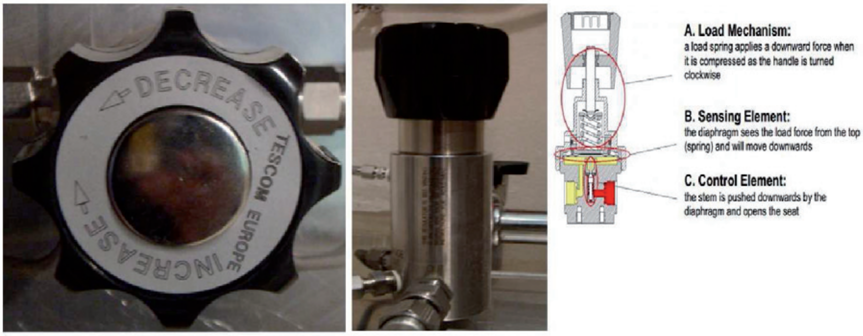



Figure 2-6: show the Pressure Reducing Regulator valve (V3)

### Safety Relief Valves (SV1 and SV2)

Two safety relief valves SV1 (see figure 2-7) and SV2 (see figure 2-8) are placed on the pressure line to the main control panel for the purpose of safety, see Appendix A2. These valves are used to protect the piping system from damage due to over pressurization. In case the system pressure rises above the set pressure, the excess force moves the piston off its seat to relieve excess pressure. The first relief valve is placed after the manual valve V2 and the second relief valve is placed after the pressure reducing valve V3 (see figure 2-4). These valves sets off only once. If they sets off, they need to replaced and sealed to continue the operations safely.


Figure 2-7: Safety Relief Valve SV1 (close-up view)


Figure 2- 8: Safety Relief Valve SV2 (close-up view)

**Electrically Operated Valves (Solenoid Valves)**

There are two electrically operated valves (solenoid valves) which are placed on the main control panel, namely; filling valve and relief valve. The filling valve is used to fill the pressurized air to the driver section of the main shock tube through the flexible pipe, see Appendix A2. The relief valve is used to release the pressurized air from the driver section of the main shock tube to the atmosphere, see Appendix A2. Both valves can be operated remotely.

These valves are in the closed position when solenoid is not activated. The bodies of the valves made of stainless steel to achieve a compact and reliable design see figure 2-9. The high quality PEEK piston guarantees a long operating life and a large temperature range. The valves can withstand a burst pressure beyond 1400 bar. More information relating to the specifications of these valves is in the Appendix A6.


Figure 2-9: Solenoid valve (close-up view)

**Pressure Measuring Devices**

Pressure measuring devices are used to collect pressure data during the shock tube experiments. The pressure measuring devices are connected on the pressurising line and on the main shock tube, see Appendix A2.

There are two types of pressure measuring devices located on the main control panel; pressure gauges (P1 and P2) and static pressure sensor (Compact pressure transducer), see figure 2-4. In addition, two dynamic pressure sensors are attached in the driven section of the shock tube. The details of this are discussed later.

**Pressure Gauges (P1 and P2)**

The pressure gauges are used to measure the correct value of the air pressure in the pressure line, see Appendix A2.

P1 is used to measure the pressure from the cylinder and can read up to 400bar. P2 is used to measure the pressure after the pressure regulating valve and can read up to 250 bar. During normal operation, P1 should not indicate pressure more than 300 bar and P2 more than 100 bar. Pressures above these limits may activate the safety relief valves (SV1 and SV2).

The pressure gauges are tested against vibration and are shock resistant. The cases of the pressure gauges are constructed from stainless steel.

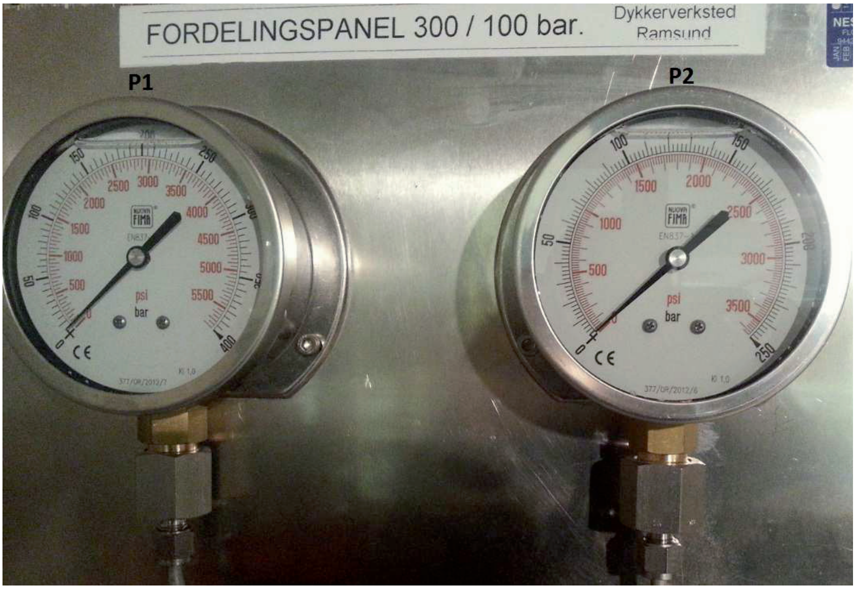



Figure 2-10: Pressure gauges (P1 and P2)

### 2.2.3 Main shock tube

The main shock tube consists of two sections, commonly referred to as the driver and the driven sections. In this setup, these two sections interact through a high-speed valve. The driver and driven sections are divided into subsections, which are connected together by flanges to make a complete set of main shock tube, see figure 2-11.

This shock tube is constructed with 316 stainless steel tubes, with thickness of 7.62 mm, weight 15.5 kg/m, outer diameter 88.9 mm and inside diameter 73.7 mm, for more details, please see Appendix A4. The shock tube fabrication details are given in Appendix A3.

When operating at 100 bar pressure the hoop stress corresponds to 58MPa, which is 20% of the yield strength of the build material giving a margin of safety of 5. This margin of safety is important in case of over-pressurizing.

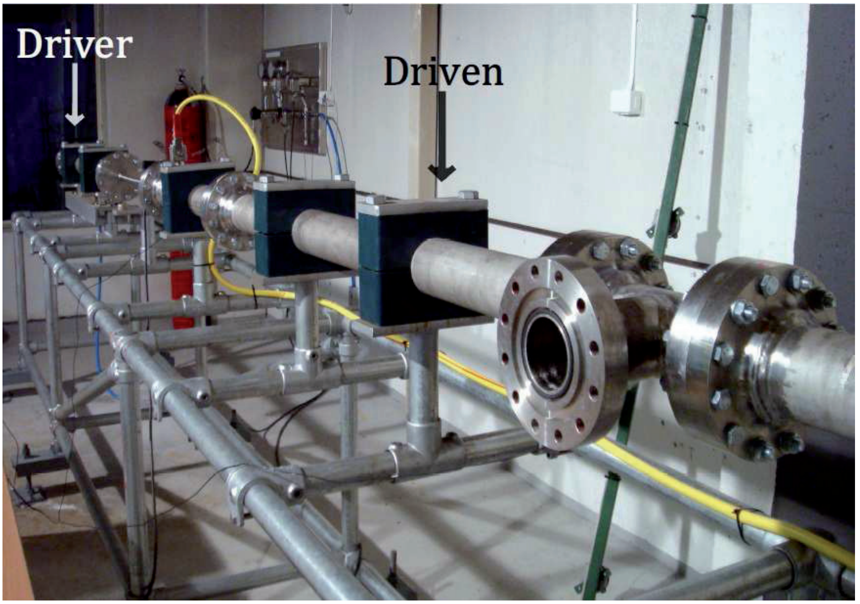


Figure 2-11: The overview of the shock tube experimental setup. Far end is high pressure section (driver). Near end is low pressure section (driven). T-section is used to mount test specimens.

The tube consists of number of movable sections. The T-Section has opening for attachment of test samples. This section can be moved to different locations (close or away from high-speed valve) to allow different pressure loadings.

Key constructional details associated with the joining of the tube subsections (S1, S2, S3, S4 and S5), are shown in figure 2-11. These joints are designed such that the strength requirements are met and the continuity of the bore is maintained without misalignment. The tube subsections are joined by flanges, which conform to the pressurised equipment (Directive 97/23/EC). These flanges are around 190 mm in diameter, held by 12 bolts, and sealed with O-rings on the faces, see figure 2-12.

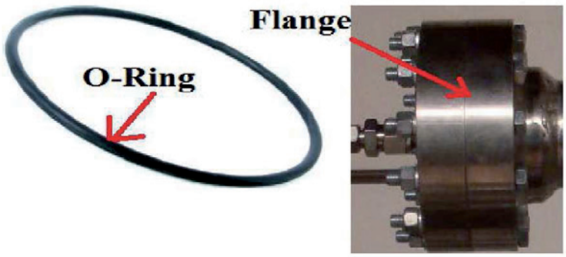



Figure 2-12: O-ring and flange

## Driver Section

This section has two subsections S1 and S2. The S1 is of the same diameter as the driven section however S2 is smaller in diameter, see figure 2-13.

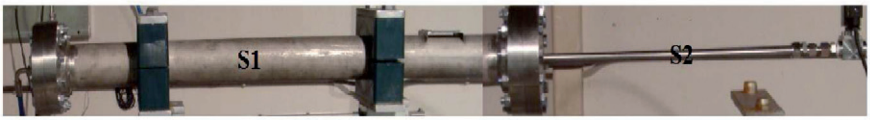



Figure 2-13: Driver Section of main tube

## Subsection S1

Refer to the schematic diagram of the shock wave tube diagram Appendix A2; S1 is the first subsection of the main shock tube and is located at the left end of driver section of the main shock wave tube. This part of the driver section is shown in figure 2-14.

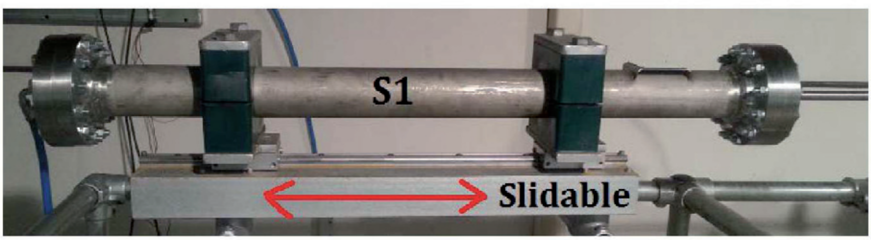



Figure 2-14: Subsection S1 of the driver section of the main shock tube

This subsection of driver section is supported by two blocks as shown in figure 2-14 and can be moved back and forth by about 200 mm. This provides an allowance in connectivity of the driver section with rest of the shock tube. This section is connected with the flexible hose pipe as shown in figure 2-15. This pipe is used to fill the driver section with the pressured air.

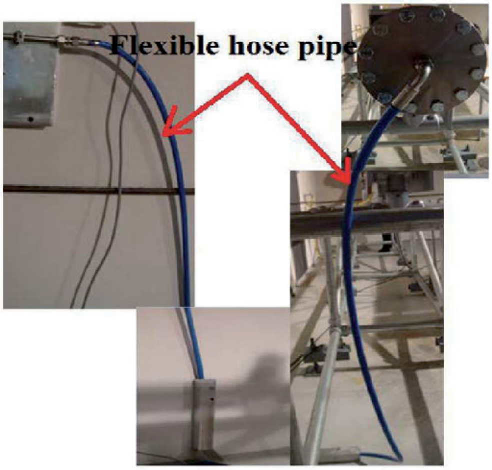



Figure 2-15: Flexible hose pipe

Subsection S2

Second subsection of the driver section has a total length of 163mm and a diameter of 22mm (approximately).This subsection is equipped with a trigger valve which is used to separate driver and driven section of the main shock tube. The material used for manufacturing S2 is 316 stainless steel.

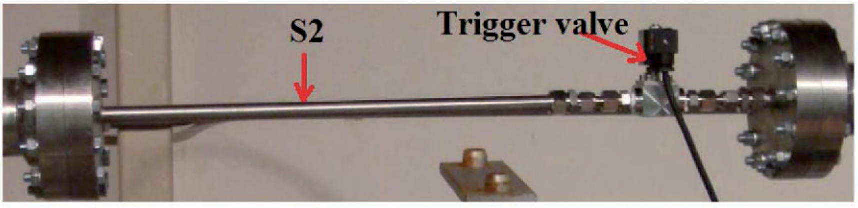



Figure 2-16: Subsection S2 of the driver section with trigger valve

Trigger valve

This is 2E series normally closed solenoid valve with a 2/2 pilot piston. The valve is located in subsection S2 of the driver section. It is at 416mm from the flange joining S2 and S1, and it is 106mm to the flange joining S2 and S3 (subsection from driven section), see figure 2-16. An electric switch activates the valve remotely. For more details, see Appendix A.

This valve is equipped with a screw (stainless steel), locking washer (stainless steel), washer (stainless steel), encapsulated coil (plastic), DIN 43650 Form A (plastic), armature tube (Stainless steel), spring, 2x(Stainless steel), plunger (Stainless steel), screws/washers, 9x (stainless steel), valve body, 3x(stainless steel), O-rings, 3x(VITON/FKM) and piston (Stainless steel W/PTFE seal), see figure 2-17.


Figure 2-17: Shows the trigger valve

Driven Section

The driven section is the largest part of the shock tube. This is the test section where the shock wave propagated and interact with test specimen. This section is about 3890mm by length.

The driven section has four subsections (S3, S4, S5 and S6). These sections are joined together by aligning the flanges and connecting through bolts, see figure 2-18.

Figure 2-18: Driven section of the shock tube

Subsection S3

This subsection of the driven section is equipped with water inlet valve (ball valve) and dynamic pressure sensor (also referred to as shock sensor), as shown on figure 2-19. This section is about 1230mm in length.

The water inlet valve (V7) and dynamic pressure sensor are highlighted in the figure 2-19.

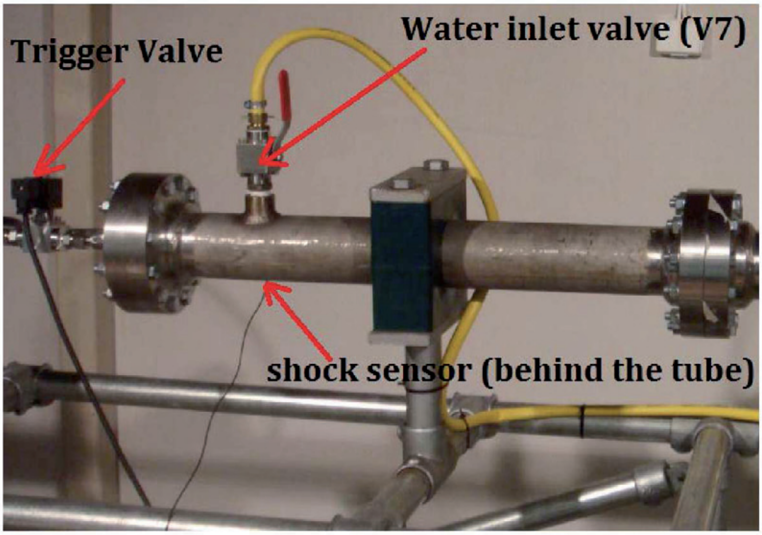



Figure 2-19: Subsection S3 with water inlet valve (V7) and dynamic pressure sensor.

Water inlet valve (V5, V6 & V7)

A sandwich style ball valves are attached with the driven section of the shocktube to fill it with water. Its pressure rating is from 1,000 psi (64 bar) to 3,000 psi (207 bar). The bolt together style series valve offers flexibility and interchangeability, see figure 2-20. It is manufactured with the choice of threaded socket or butt weld ends for installing the valve into the pipeline. This valve is constructed from 316 stainless steel. After installation, the valve is easily maintained by removal of the centre section where new seats and seals can be replaced in order to prolong the valve life. The design features relating to this valve are given in Appendix A5.

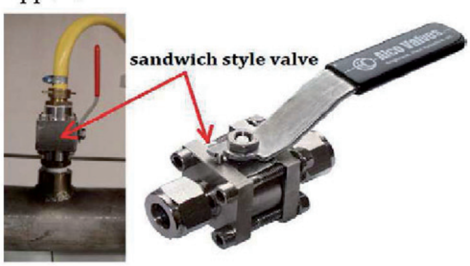



Figure 2-20: Sandwich style valve

Subsection S4

This is the second subsection of the driven section. This subsection is 1440 mm long. More details are given in Appendix A3.

Figure 2-21: Subsection S4 of the driven section

Subsection S5

The Tee section S5 is used to mount test specimens. This subsection could be moved to different locations in the driven section to allow for the different shock loads.

This subsection has three flanges (one at each end of 'T') as shown in figure 2-22. The Tee section is equipped with a shock sensor (Piezoelectric pressure transducer at Boss 2) and strain gauges which are mounted on the centre of the test specimen (see figure 2-22).

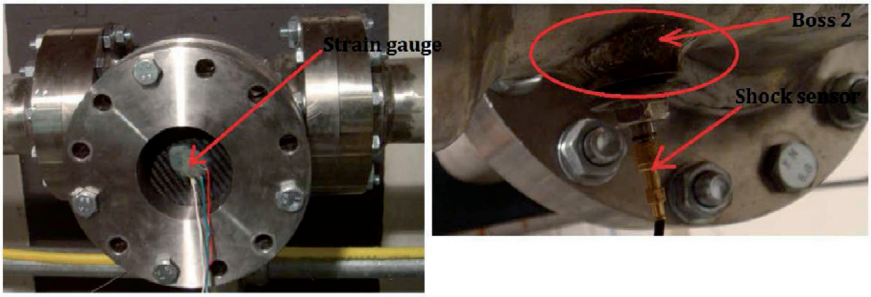



Figure 2-22: Tee-Section mounted with carbon fibre test specimen. A rosette strain gauge is placed in the centre. A pressure transducer is placed at boss2.

### Piezoelectric Pressure transducer at boss 2

The piezoelectric pressure transducer at boss 2 as shown on figure 2-22, is used for monitoring the pressure profile just before the test specimen. Features and specifications of piezoelectric pressure transducer is given in Appendix A8.

### Subsection S6

This is the last subsection of the driven section of the main shock wave tube, see Appendix A2. The subsection is 1440 mm in length and it has the rupture face at the end, see figure 2-23.

This subsection was equipped with two ball valves v5 and v6 (ball valves) at the left end of the main shock tube, see figure 2-23.

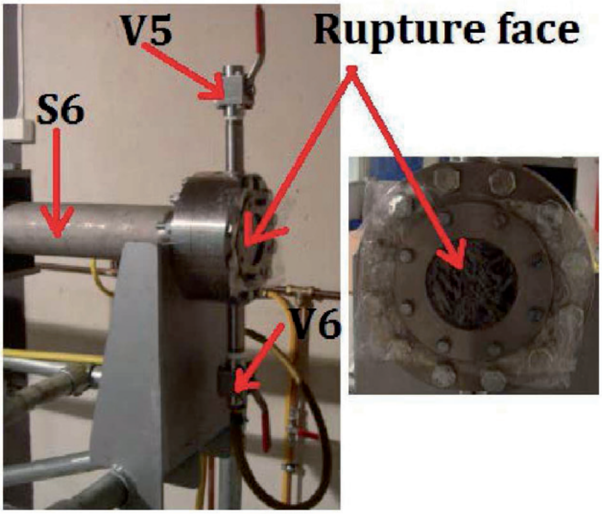


Figure 2-23: Subsection S5 and the rupture face at the end of the main shock tube

### Shock tube supports

Shock tube supports are used to hold the main shock tube to its aligned position. These supports are simple and robust and made of tubes and key clamps, see figure 2-24.

Each section of the shock tube is associated with the table section. Each table section provides two support arms and pipe clamps which are locked around the shock tube. These support arms allows variation in height, which enables slight elevation of one end of the shock tube.

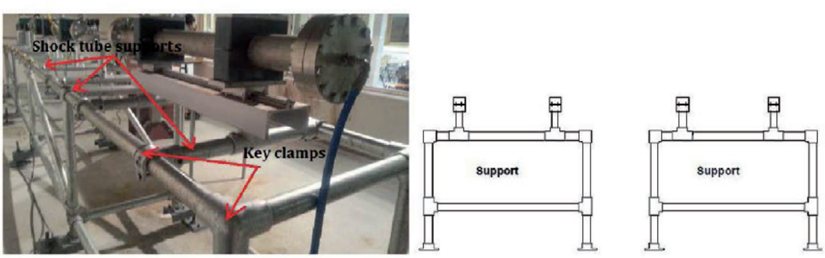


Figure 2-24: Shock tube support

2.2.4 Electronic components and gauges

Static Pressure Sensor

This is 3100 Series model Compact High Pressure OEM Pressure Transmitter. The transducer has a small size, light weight, static calibration, high stiffness and wide frequency range. The transducer is constructed from stainless steel with robust, compact design that resists pressure spikes, shock and vibration. This sensor has also variety of pressure ranges, process connections, electrical connections and output signals for system versatility, see Appendix A7.


Figure 2- 25: Compact pressure transducer

Static pressure sensor is attached in shock tube in given circuit, see figure 2-26 below.

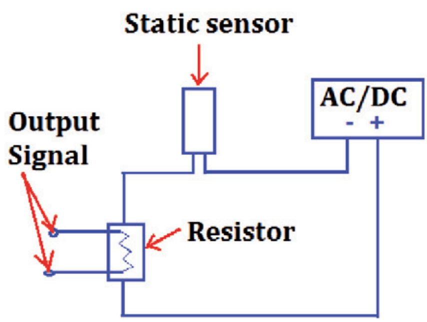



Figure 2-26: Circuit for Static sensor attached in shock tube

AC/DC power supply used is shown in figure 2-27. Resistor connected in circuit (figure 2-26) is shown as follows in figure 2-28,

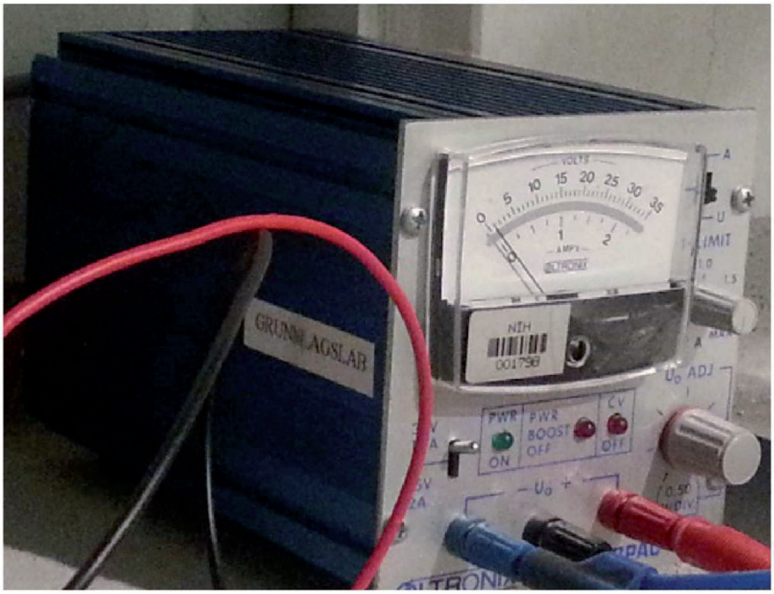



Figure 2-27: AC/DC Converter

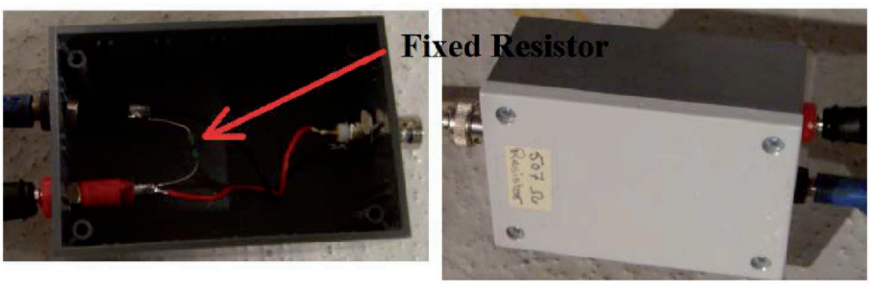



Figure 2-28: Fixed resistor

### Piezoelectric Pressure transducer at boss 1

The Piezoelectric pressure transducer at boss 1 is placed right after the trigger valve. This sensor is first to sense the shock pressures in the driven section of the shock. Due to this reason, it is used to trigger the data gathering process. The piezoelectric pressure transducer at boss 1 is shown in figure 2-29.


Figure 2-29: shows piezoelectric pressure transducer and boss 1

This was CY-YD-205 Model, pressure transducer which was characterized by having small size, light weight (10g), static calibration, easy mounting, high stiffness, natural resonance frequency ⩾ 1000kHz, capacitance (at 1000 Hz) 7 pF and 4-20mA current output, see Appendix A8.

Charge amplifier (Amp 1 and Amp 2)

These charge amplifiers are used to amplify the pressure signals from piezoelectric pressure transducers located on the driven section of the shock tube. These two amplifiers are YE5856 models. They have upper frequency limit up to 500 kHz, low size with high integration, three decimal-system uniformisation outputs, built-in multiple low pass and high filters, low noise with high precision, charge and voltage input, and overload indication. The data specifications for these amplifiers is given in Appendix A10.

Figure 2-31: YE5856 Charge Amplifies

Wheatstone bridge Circuit

The Wheatstone bridge circuit is connected with strain gauge to make a combination of a single gauge (Quarter Bridge), see figure 2-32. In the quarter circuits, the bridge is completed with precision resistors. The complete Wheatstone bridge is excited with 7.76V DC supply. Wheatstone has three pots for channels 4, 5 and 6 as shown on figure 2-32.

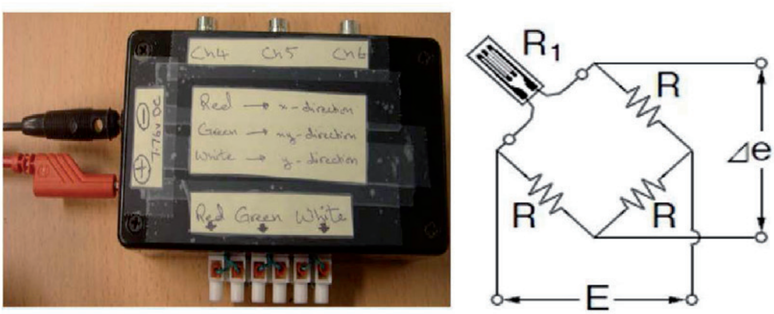


Figure 2-32: External and Internal of Wheatstone bridge circuit

### Terminal Block

This terminal block is used to connect cables from static pressure sensor and piezoelectric pressure transducers to the DAQ (Data Acquisition) system.

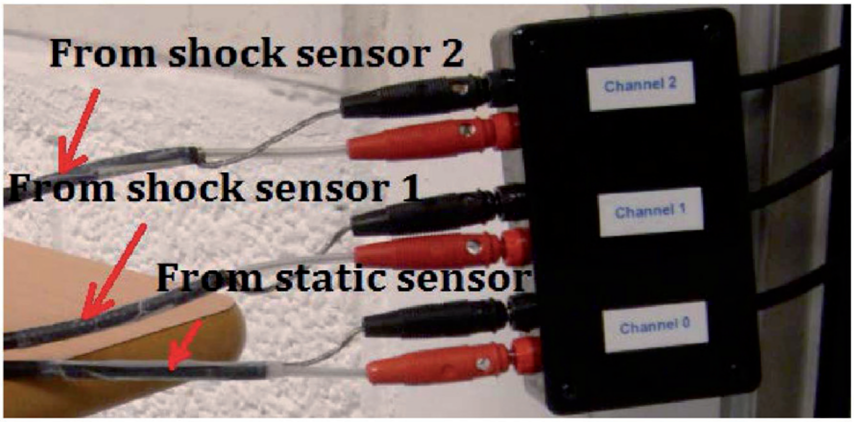


Figure 2-33: Terminal block

### Remote control switch

The remote control switch has three switches; for activating the trigger valve, filling the driver section with pressurised air through solenoid valve and releasing pressurised air from the driver section through solenoid valve. Remote control switch is shown in figure 2-34.

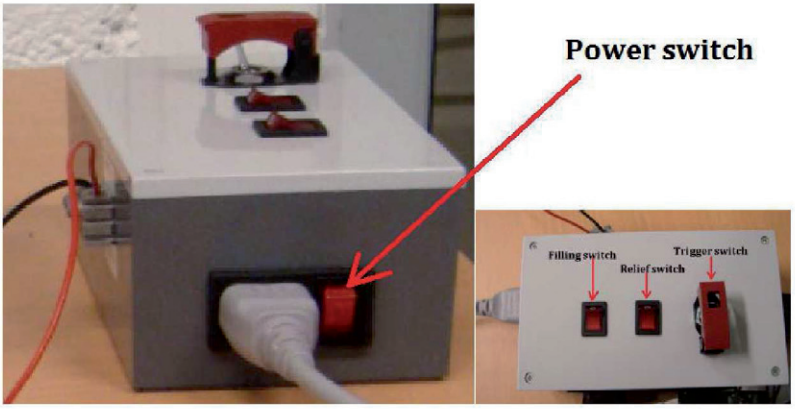


Figure 2-34: Remote control switch

Electric extension lead

To power different systems at various location of shock tube, water proof electric extension lead are used as shown in figure 2-35.

Figure 2-35: Electric power extension lead

2.2.5 DAQ device

This is NI USB-6351 model, X Series Data Acquisition device. DAQ device is used to digitize signals by performing analogue to digital (A2D) conversions. The general X series block diagram for DAQ devices is shown in Figure 2-36.

Following are the characteristics of this device:

- 16 analogue inputs, 1.25 MS/s 1-channel, 1 MS/s multichannel; 16-bit resolution; ±10V
- Two analogue outputs, 2.86MS/s, 16-bit resolution, ±10V
- 24 digital I/O lines (8 hardware-timed up to 1 MHZ)
- Four 32-bit counter/timers for PVM, encoder frequency, event counting, and more
- Advanced timing and triggering with NI-STC3 timing and synchronization technology
- Support for windows 7/vista/ XP

Figure 2-36: NI USB-6351

DAQ System Overview

The typical DAQ system is shown in figure 2-37. This DAQ system consists of sensors, transducers, cables, accessories, DAQ hardware, DAQ software and personal computer.

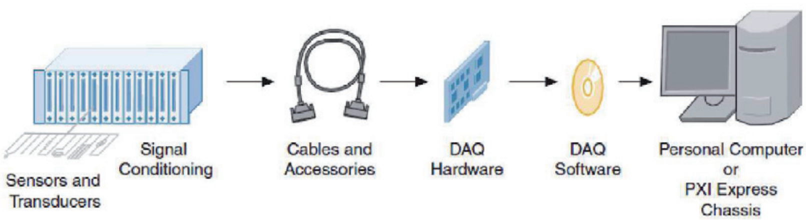



Figure 2-37: Components of a typical DAQ System

Sensors and transducers

These are static pressure sensor, piezoelectric pressure transducers and strain gauges. These sensors and transducers are located on the driven section of the shock tube.

Cable and accessories

Various cables and connecting accessories are used to connect the sensors with the DAQ system. An example is shown in figure 2-28.

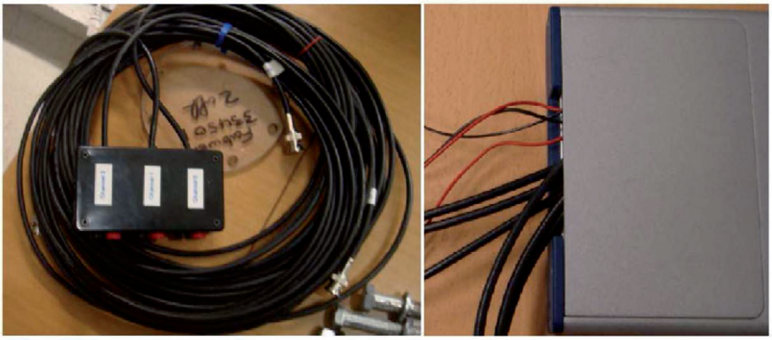


Figure 2-38: Cables and accessories

### 2.2.6 Application Software

LabVIEW Signal Express® software is installed in the computer to aid the pre-sensor checks. This is used to identify the loose connections if existed by showing unusual noise in the signals. This is an important process for capturing the reliable experimental data.

The LabVIEW application software with NI-DAQmx driver software is installed in the computer as a platform and development environment for a visual programming using LabVIEW®. The software includes a set of items that allows the user to configure, acquire data, and send data to DAQ device.

An additional calibration and data analysis software program is implemented for the purpose of converting the units from recorded data to actual parameters. During the experiments, all of the collected data is in voltages which needs conversion using various calibration correlations.

# Chapter 3: Safety, Limitation of Usage and Risk Assessment

## 3.1 Introduction

This chapter describes the safety, limitation of usage and risk assessment of the working place on the shock wave tube testing facility. Much of the chapter is devoted to describe the importance of safety in the working place, risk management, risk assessment, electrical safety training requirements and the guidelines relating to the safety in operating the shock tube. The test, verification, approval and certification of the equipment in the shock tube setup facility are also covered.

Safety is for both people and environment. It involves people and productivity and the costs of managing each. It involves coordinating policies and operations with industry standards and practices according to government regulation.

## 3.2 The importance of safety in the working place

Safety in the workplace is the arrangement of all equipment for insuring safety and absence of risks to the health in connection with the use, handling and storage of equipment. Safety saves lives and money while increasing trust and teamwork. Any ethical work place will place a high emphasis on safety if it values its employees and future existence.

In order to meet the basic safety requirement, equipment must be designed and manufactured such that it protects against risk of damage to persons by electrical shock and other hazards, and against resulting fire and explosion.

To ensure safe plant operation, the performance of all levels of safety system needs to be reconsidered. Besides the organizational and process control measures to maintain safe plant operation, the last stage of protection of process equipment against excess pressure is often through the use of a mechanical self-activated devices. These devices, a safety relief valve or bursting disc, are mostly installed on top of the pressurized system.

### 3.2.1 Accidents and their consequence

Any accident in a person injury causes pain to the victim and disruption to the project. In purely economic terms, the organization may have to bear significant costs. This may cause delays in operation hence delay in deliverables .Delays are likely to have an immediate impact on performance and a poor safety record will worsen this problem through damage to the organization's reputation .

**Why do accidents happen?**

Most accidents and unpleasant incidents at workplace are caused either directly or indirectly, by human error. They might be a result of an unsafe act by an individual, unsafe working condition (also ultimately attributable to human error) or a combination of the two.

**Why do people on the workplace commit to many unsafe acts?**

One or more of the following factors are usually involved.

- Failure to follow the correct procedure
- Inadequate training
- Stress
- Fatigue and
- Lack of motivation

### 3.2.2 The contribution to safety by workers on the working place

All who work on the working place are responsible for safety, both for themselves and others. In order to fulfil these responsibilities, each member on the working place should:

- Always use common sense for their safety and for the safety of those around them.
- Familiarize themselves with and always follow the general rules which apply to a particular work place
- Familiarize themselves with and always follow the safety practices which apply to a particular job
- Make sure that appliances are fit for the work to be undertaken
- Familiarize themselves and always follow safe operating procedures for the equipment at all time
- Promptly report unsafe equipment conditions or operations

- Contribute positive safety ideas to those responsible

Remember, any participant on the working place has the duty to intervene if they think something is unsafe. No member in the working place is obliged to carry out unsafe acts or to work in unsafe conditions.

### 3.3 Risk management: The key to cost containment

Workplace accidents can happen. Such accidents, however, can be prevented or minimized through effective risk management program. Risk management involves:

- Identifying hazards and potential hazards
- Taking action to reduce and/ or eliminate them.

Taking such action minimized employers exposure to liability, losses resulting from workers' compensation claims, and hidden losses resulting from production downtime, employee absence and replacement and/or job reassignment.

#### 3.3.1 Cost containment strategies

All workers loss from workplace accident or illness. Controlling these losses involve understanding various strategies that include:

- Developing management awareness programs
- Installing employee involvement programming
- Investigating accidents and incidents
- Conducting safety audits
- Managing the claims process
- Managing litigation

#### 3.3.2 Safety Regulations and Facility liability

Poor safety practices can result in many direct and hidden costs to the employer's bottom line, including penalties for non-compliance with OSHA standards and the higher cost of insurance premiums. For these reasons, it pays facility managers to know how OSHA makes its standards, what safety and health regulations are on the reports and are in process of change, and key liability issues.

3.4 The Organization management role on the effective safety management

The management team must take a proactive approach towards identifying hazards and developing measures to reduce risks to the minimum level at work place.

Safety management needs to be carried out in a systematic way on the working place. This involves:

- Developing and refining safety management systems
- Managing safe operation and maintenance
- Creating a safety culture
- Training and familiarization
- Motivating and leading

The continuous improvement cycle

Effective safety management means taking a proactive attitude towards reviewing and correcting anything that could pose a risk.

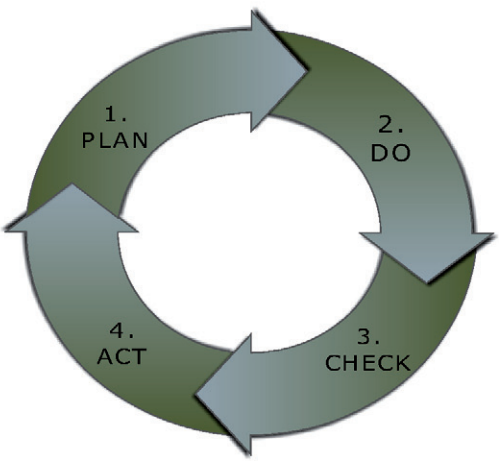



Figure 3-1: Continuous Improvement cycle

The continuous improvement cycle is a management tool in which policy in planned and set, management processes are implemented, their effectiveness is measured, and any adjustments are made, before the whole cycle begins again

- The team identifies the risk element(s) in an activity or piece of equipment
- A plan is agreed to implement a new measure which will address the risk(s)
- The measure is then assessed and refined
- Based on the findings, an improved measure is agreed and implemented
- The improved measure is assessed and refined.

**3.5 Routine Operation**

All routine operations that could have safety implications should be managed, and part of the management process involves assessing them for risk (this is dealt with in detail under risk assessment)

Each aspect of the operations must be planned in detail, and carefully scheduled to ensure there are enough people for the task and that it will not conflict with other operations taking place at the same time.

The most efficient approach to delegating tasks is to plan and prioritize them in advances, preferably in a meeting with the relevant personnel:

- What tasks need to be done?
- When do they need to be done?
- If there are too many to do at once, can one of them be off to a later time?
- If not, what would be the most appropriate task for you, personally, to be taking control of?
- Who would be the most suitable supervisor(s) to take on the other task(s)? Have they been trained in how to do this? Do they have sufficient experience?
- What feedback mechanism can be used to ensure that job is being done properly?

**3.6 Record keeping**

Record keeping is an important part of the safety management system for routine operation and essential for auditing purposes. Has the operation been safely planned? Has it been checked? Has equipment been safely and regularly maintained? All these things should be recorded .

### 3.7 Risk Assessment

Risk assessment is an essential aspect of safety management. It can be applied to any procedure or equipment, and really does reduce the risk of accidents.

The obvious use of risk assessment is to find out what risk might be attached to a new task or piece of machinery. Yet one of the most useful applications is on existing working practices which have always been done in a particular way. Because people have become used to do it on that way, they do not see how potentially dangerous it is.

There are no fixed rules for how to perform a risk assessment, but it is strongly recommended that, the organization set up a procedure for doing this and for ensuring that risk assessments are recorded, put into action and evaluated.

#### 3.7.1 How to manage a successful risk assessment

- Plan. What needs to be done? Who is going to do it? Will it need a written assessment? Will it need a permit to work? (Usually for work on pressurized equipment, work requirement isolation from sources of electrical power).

- Hold a briefing meeting with everyone who will be involved. Explain why the risk assessment is being carried out. Remind people about risk and precautions and check that they are properly prepared, and wearing the appropriate Personal Protective Equipment (PPE). Don't forget to ask for the participant opinions and suggestions, and praise good idea. This is good management and helps to create a safety culture.

- Identify the hazards inherent in the procedure or equipment, and evaluate the severity of the level of risk.
- Decide what would be the best course of action to take. Have a contingency plan in case something unforeseen happens.

- Communicate the work plan throughout the working place. Everyone on the working place should know what other people are doing.
- Before starting the task, hold the 'toolbox talk' (an on-the-job-briefing) to ensure everyone understands the task to be done, what is required of them, and has the correct tools, PPE and permit to work
- Carry out the agreed action
- Monitor what has been done. Has it been successful? Could it be improved?

### 3.7.2 The importance of risk assessment

The purpose of risk assessment process is to remove a hazard or reduce the level of its risk by adding precautions or control measures, as necessary. By doing so, the workplace is created to be safer and healthier.

### 3.7.3 The ways of doing the risk assessment

The assessments should be done by a competent team of individuals who have a good working knowledge of the workplace. The staff should be involved always include supervisors and workers who work with the process under review as they are most familiar with the operation.

In general, to the assessment, the following steps should be considered:

- Identify hazards
- Evaluate the likelihood of an injury or illness occurring, and its severity
- Consider normal operational situations as well as non-standard events such as shutdowns, power outage, emergencies, etc.
- Review all available health and safety information about the hazard such as MSDSs, manufactures literature, information from reputable organizations, results of testing, etc.
- Identify action necessary to eliminate or control the risk
- Monitor and evaluate to confirm the risk is controlled
- Keep any documentation or records that may be necessary. Documentation may include detailing the process used to access the risk, outlining any evaluations, or detecting how conclusions were made.

## 3.8 Limitation for the usage of Equipment

Shock wave tube operates at high pressures can cause explosion and produce violent shock waves if the pressure of air in the system will exceed the given limit. To avoid catastrophic failure, it was recommended to have the control and safety valves in the pressure lines to limit the excess pressure. In addition on that, the protection principles and non –technical measures are defined for the purpose of safety.

## 3.9 Protection Principles

Protection principles are defined as the way of excluding the equipment and component as the ignition source in the plant. The ignition sources which are caused by sparks from friction or impact or from electro-static charging have to be prevented by selecting appropriate materials and by constructive measures. This must be verified and confirmed by the appropriate tests, Appendix B1.

The protection principles can be equally applied to electrical and non-electrical devices and for gases and for dusts.

### 3.9.1 Personal Protective Equipment

The Personal Protective Equipment Standard (PPE) was revised in April, 1994 . The purpose for the revision was to update the standard to reflect current technological improvements to personal protective equipment; conduct assessments to determine the presence of actual and potential hazards (including those created by impact, compression, penetration, heat, chemicals, harmful dust and light radiation) which necessitate or would necessitate the use of personal protective equipment; and provide employee training in the use of personal protective equipment.

The PPE now requires that employers certify in writing that, they have performed the assessment, and verify in writing that employees have been trained on and understand the necessity use, limitations and proper care and maintenance of personal protective equipment. The written certification must:

- Identify the worksite evaluated
- List the dates the assessment was performed

- Specify that the written document is a certification of the assessment.

The effective compliance dates for the revised PPE were July 5, 1994 for the PPE upgrades, and October 5, 1994 for the hazard assessment and training requirements.

### 3.9.2 Non-technical measures

The requisite preconditions for the safe operation of electrical equipment in potentially explosive atmospheres are created in a joint effort by the manufactures of explosion protected equipment, the constructors and operators of the plant. It is important that, the operator of such plant should ensure that, their personnel know how the danger of explosions is likely to arise and measures that are to be taken to prevent it. The employees should be regularly trained on the contents of the explosion protection document in accordance with Directive 1999/92/EC (Occupational safety regulations) and informed by means of written corporate regulations which should be regularly updated, Appendix B2.

## 3.10 Electrical safety training requirements

Workers near energized, or potentially energized electrical circuitry of fifty (50)-volts to ground or greater, shall be trained in energized electrical safe work practices and procedures, and retrained as necessary (PDEs).

The responsible persons in the plant must receive training in avoiding the electrical hazards associated with working on or near exposed energized electrical work, such training will be provided when the person is initially assigned to the job and refresher training will be provided every three years or when conditions changes (PDEs).

The following items are to be included in the training of Qualified Electrical persons (PDEs).

- Demonstrate a working knowledge of the National Electrical Code
- Universal electrical safety procedures
- Skills and techniques necessary to distinguish exposed live parts from other parts of electrical workers.

- Perform on-the-job training with a qualified electrical worker
- Selection and use of proper work practices, personal protective equipment, tools insulating and shielding materials and equipment for working on or near energized parts.

Qualified Electrical person must also be trained in recognizing signs and symptoms of electric shock, heart fibrillation, electric burns, and proper first aid protocols for these conditions (PDEs).

### 3.10.1 Portable electrical equipment and extension cords

The following requirements apply to the use of cord and-plug-connected equipment and flexible cord set (extension cords) (PDEs).

- Extension cords may only be used to provide temporary power.
- Portable cord-and-plug connected equipment and extension cords must be visually inspected before use on any shift for external defects such as loose parts, deformed and missing pins, or damage to outer jacket or insulation, and for possible internal damage such as pinched or crushed outer jacket. Any defective cord or cord-and-plug connected equipment must be removed from service and no person may use it until it is removed from service and no person may use it until it is repaired and tested to insure it is safe for use.
- Extension cords must be of three wire type. Extension cords and flexible cords must be designed for hard or extra hard usage (for example, type S, ST, and SO). The rating or approval must be visible.
- Portable equipment must be handled in a manner that will not cause damage. Flexible electric cords connected to equipment may not be used for raising or lowering the equipment.
- Extension cords must be protected from damage. Sharp corners and projects must be avoided. Flexible cord may not be run through windows or doors unless protected from damage, and then only on temporary basis. Flexible cords may not be run above ceiling or inside or through walls, ceiling or floors, and may not be fastened with staples or otherwise hung in such a fashion as to damage the outer jacket or insulation.
- Persons' hands must be dry when plugging and unplugging flexible cords and cord-and-plug connected equipment if energized equipment is involved.

### 3.10.2 Working on de-energized equipment

In working on de-energized equipment, the most important principle of electrical safety is to assume that all electric circuits are energized unless each involved worker ensures they are not.

Every circuit and conductor must be tested every time work is done on them. Proper PPE must be worn until the equipment is proven to be de-energized.

- Voltage rated gloves and leather protectors should be worn
- Electrically insulated shoes should be worn
- Safety glass must be worn
- The required Arc Flash PPE must also be worn

**The National Fire Protection Association (NFPA)**

The National Fire Protection Association lists six steps to ensure conditions for electrically safe work.

- Identify all sources of power to the equipment. Check applicable up-to-data drawings, diagrams, and identification tags.
- Remove the load current, and then open the disconnecting devices for each power source.
- Where possible, visually verify that blades of disconnecting devices are fully open or that draw out type circuit breakers are fully withdrawn
- Apply lockout/tag out devices in accordance with a formal, written policy.
- Test each phase conductor or circuit part with an adequately rated voltage detector to verify that, the equipment is de-energized. Test each phase conductor or circuit part both phase-to-phase and phase-to-ground. Check the voltage detector before and after each test to be sure that it is working.
- Properly ground all possible sources of induced voltage and stored electric energy (such as, capacity) before touching. If conductors or circuit parts that are being de-energized could contact other exposed conductors or circuit parts, apply ground-connecting devices rated for the available fault current.

- The process of de-energizing is a “live” work and can result in an arc flash due to equipment failure. When de-energizing, the following procedures as described in “Working On or Near Live Equipment.
- Before beginning work relating to the electrical equipment, each involved person must verify through testing that all energy source have been de-energized
- Return to service. Once work is completed and lockout/tag out devices removed tests and visual inspected must confirm that all tools, mechanical restraints, electric jumpers, shorts, and grounds have been removed. Only then, it is safe to re-energize and return to service. Persons who are responsible for operating the equipment and needed to safety re-energize it should be out of the danger zone before the equipment is re-energized.

### 3.11 The guidelines relating to the safety requirements during the operation

In order to control safety for those who working on the shock wave tube laboratory, the following guidelines should be adhered to in operating the shock tube:

- Personnel should not be in the vicinity of the tube when the driver section is pressurized.
- Pressurizing of the tube should be carried out from a remote location
- De-pressurizing (Venting) of the tube through the vent (relief valve) should be carried out remotely.
- The tube should always be operated with the safety relief valve in place
- The safety relief valve should undergo periodic checks to ensure that it operates as its normal set pressure.
- Opening of the driver section by the unlocking of driver section flange bolts should be carried out with the vent valve open.

### 3.12 The OSHA inspection

The Occupational Safety and Health Administration (OSHA) were authorized by the OSH Act of 1970 to conduct workplace inspections. These inspections are carried out to determine whether employers are complying with Agency Standard as well as to enforce section 5(s) (1) of the OSH Act, commonly known as the General Duty Clause.

### 3.13 Test, verification, approval and certification of the equipment

In order to meet the safety standard requirements, the shock wave tube equipment were tested by qualified companies. The testing companies offered the certificates as verification and approval for the equipment after being qualified. The following equipment was tested in the shock wave tube test facility and then approved.

#### 3.13.1 Stainless steel shock tube

The hydrostatic pressure test was conducted to the stainless steel shock tube by FABWELD QUALITY FABRICATION on 21/03/2011. The testing equipment was hand pump; testing medium was water under pressure of 150Bar for the duration of 30 minutes. The FABWELD QUALITY FABRICATIONS was satisfied with equipment by hydrostatically test in accordance with Quality Control Procedure, Appendix B7.

Then on 27/04/2011 ZURICH ENGINEERING certified that, the pressure equipment (shock tube) was subjected to EC unit verification, including examination during and upon completion of manufacture, as required by the Code of construction and inspection specification. This was found to meet with the provisions of the pressure Equipment Regulations 19999, Appendix B8.

#### 3.13.2 Compressed air cylinder

The compressed air cylinder was tested on 20/06/2012 by FLO/TV- MAR-Quality System. The test was based on the volume capacity of the cylinder (50.7litre), working pressure (300bar), testing pressure (450bar) and weight (74.4kg).

During such testing, the air bottle was also inspected for rusting and approved that, there was no rust. The new bottle valve was fitted and then, the bottle approved to be used on compressed air of maximum pressure up to 300bar, Appendix B3.

The bottle passed the applicable requirements under pressure testing and approved to meet the safety standard, Appendix B3.

### 3.13.3 Solenoid valves

The test report for the solenoid valves was given by KEMA Quality B.V with KEMA No. 210962800, Appendix B4/B5. The equipment (solenoid valves) have been found to comply with Essential Health and Safety Requirements relating to the design and construction of equipment and protective systems intended for use in potentially explosive atmospheres given in Annex II to the directive, see Appendix B.

The annex II states that, for the special condition of the safety use, the solenoid valves shall be protected by a suitably rated fuse, capable of interrupting the protective short circuit current.

The compliance with the Essential Health and Safety Requirements has been assumed by compliance with: EN 60079-0:2006 EN 60079-7:2007 EN 60079-18:2004 EN 61241-0:2006 EN 61241-1:2004.

The actual ambient temperature for properly working of the valves was marked to be within the limits between -200 ºC to +400 ºC, Appendix B4-B5.

### 3.13.4 Piezoelectric pressure transducer

SINOCERA Piezotronics, Inc. tested the pressure transducers on 29/07/2011. The test was based on charge sensitivity, linear range, capacitance, insulations resistance, resonance frequency, non-linearity and repeatability. All components in the transducers were approved to meet the standard of safety and the certificate offered by the company, Appendix B4.

### 3.13.5 High Pressure Transducer

These types of pressure transducers from Gems Sensors & Control are tested and supplied in accordance with published specifications or individual special requirements that are agreed in writing at a time of order. They are constructed so as not to affect adversely the safety of persons and property when properly installed, maintained and used by qualified personnel, in the applications for which they were designed and manufactured, Appendix B4.

The series 3100/3200 with the CE Mark conform to the essential protection requirements of the EMC Directive 89/33/EEC certified by type testing to EN50062-2 & EN50081-1, Appendix B6.

The series 3100/3200 with the CE0086 mark also complies with the requirements of the Pressure Regulation 1999 and is classed as a safety accessory and can be used as safety related device on Category IV pressure equipment, Appendix B6.

The following are general instructions relating to safety on the high pressure transducers, Appendix B6.

- Transducer should not be subjected to mechanical impact
- Transducer should not be subjected to greater than maximum allowable pressure (P.S)/Temperature (T.S) where defined on the transducer labor
- In the event of fire the end user must ensure that, the system pressure is vented to a safe area
- The transducer has no means of draining or venting, this must be performed by another component in the end users systems.
- Pressure range must be compatible with the maximum being measured
- Liquid must not be allowed to freeze in the pressure part.
- The gasket must be fitted under the electrical connector.
- Supply voltage must not exceed the value stated on the unit label.

### 3.13.6 Strain gauge

In order to control the standard on limitation of usage and safety requirement for the strain gauge, the FLO/TV/MAR-NORD SIVILE OPPDAG RO was inspected the strain gauges and approved that, they met the standard of requirement, Appendix B4.

## Chapter 4: Standard Operating Procedures (SOP)

### 4.1 Introduction

This chapter describes the Standard Operating Procedure (SOPs) for the shock tube setup. Much of the chapter is devoted to describe the general operation of the shock tube together with descriptions of equipment. The chapter includes checklists for devices such as pressurised air cylinder, valves, pressure gauges, specimen on T-section, the driver section, the driven section, the open end of the driven section, and control panel.

The method for collection of experimental data and procedures for processing and analysing those data by using DAQ system are also covered in this chapter.

### 4.2 General operation of shock wave tube

The shock wave tube was operated by various manual valves such as V1 and V2, and solenoid valves (filling, relief and trigger valves), see figure 4-1. Further there were safety relief valves such as SV1 and SV2 as shown in figure 4-1 for safety of personal. There were also three pressure sensors (one static sensor and two dynamic sensors) on the shock tube, see figure 2-25, and figure 2-29.

Manual valves V1, V2, V3, and V4 as shown in figure 4-1 were used to pressurize air in the steel tubing which was located on the control panel. The process of pressurizing air to the driver section was done through the filling valve; see figure 4-1. V7, V6, and V5 were also manually operated valves as shown in figure 4-1 on the driven section of the main shock tube, see Appendix A1. V7 was used to fill water in the driven section under atmospheric pressure while V5 was used to remove residual air bubbles, since the main shock oriented with the downstream and slightly elevated, so air bubbles were collected at the end of the driven section. V6 was used to drain water from the driven section after having finished the experimental activities.

The relief valve as shown in figure 4-1 was used to release the compressed air pressure on the driver section after having finished the test.

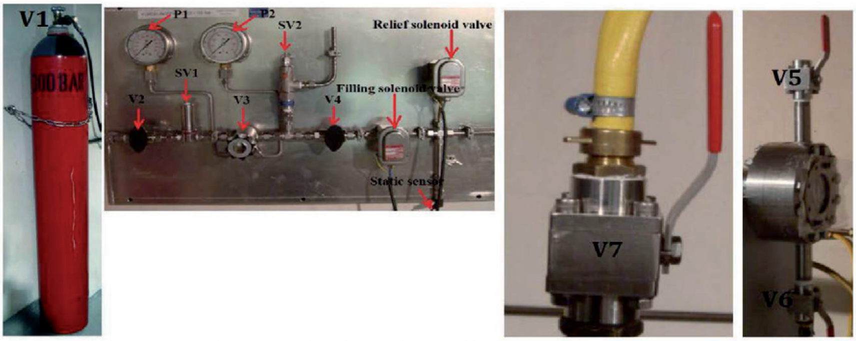



Figure 4-1: Manual operated valves (V1, V2, and V4), Pressure regulator valve manually operated (V3,) safety relief valves (SV1, SV2), pressure gauges (P1, P2), Solenoid valves (filling valve, Relief valve), and water valves manually operated (V5, V7).

The pressure gauges P1 and P2 as shown in figure 4-1 were used to measure the pressure of compressed air. The gauge P1 measured the compressed air pressure from the air bottle after having opened valves V1 and V2 which was rated up to 100bar.

Safety relief valves SV1 and SV2 (See figure 4-1) were used to control the excess pressure in the system. These two valves were activated by the compressed gas pressure when exceeded the stated limit, SV1 sets for 300bar and SV2 sets for 100bar.

### 4.3 Instrumentation (Static sensor, dynamic sensors, and Strain gauges)

Three pressure sensors and three strain gauges are the instrumentation devices which were used on collecting pressure and shock signals respectively and sending them to the DAQ device during the shock tube experiments.

The static sensor (Compact Pressure Transducer) and two dynamic sensors (Piezoelectric Pressure Transducers) were used for pressure measurements, while strain gauges were used for strain measurement. The operation of sensors and strain gauges on shock tube setup will be described on the following sections.

Static Sensor (Compact Pressure Transducer)

This pressure sensor was used to send amperage signal to the personal computer through fixed Resistor box (R), Terminal block, and DAQ device, see figure 4-2. The transducer was supplied by voltage rated 10V to 30V DC from AC to DC converter, see figure 2-26 below.

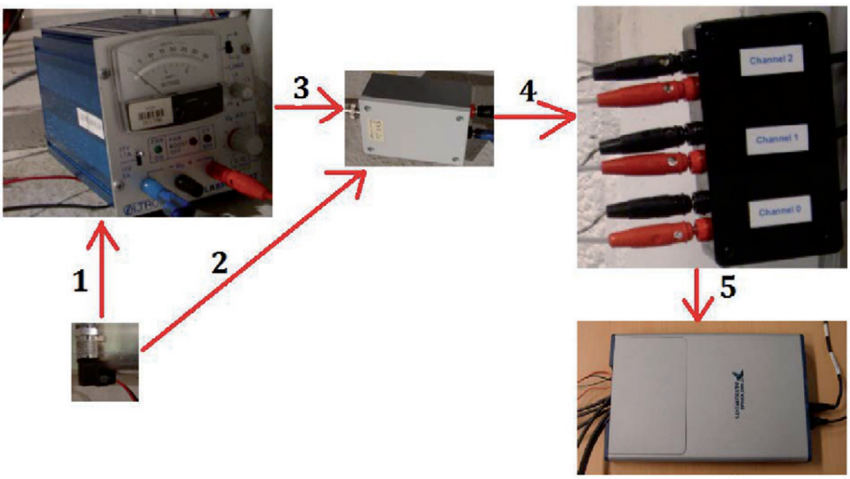



Figure 4-2: shows Static Sensor (Compact Pressure Transducer); AC to DC Converter; Fixed resistor box; Terminal block and DAQ device.

The transducer should be installed according to the manufacture instructions, and not be removed whilst the system is at pressure. Before applying power, the correct polarity and excitation should be checked.

Dynamic Pressure Sensors (Piezoelectric pressure transducers)

Dynamic pressure measurements were often taken by using two dynamic pressure sensors (piezoelectric pressure sensors) because of their microsecond rise time and high resonant frequencies . They were well suited for dynamic measurements, but the charges built-up in the piezoelectric crystal were eventually decayed to zero based upon a specified time constant. Two transient pressure monitoring locations were provided on the driven section of main shock tube at Boss 1 and 2; see figure 4-3.Both two Bosses have threads for specific piezoelectric pressure transducers. The transducer at Boss1 was used to collect pressure data from the initial stage of the shock pressure after having opened the trigger valve, while the piezoelectric at Boss2 was used to collect the pressure data down the shock tube. Both piezoelectric pressure transducers were connected to the two respectively charge amplifiers.

The charge amplifiers were used to amplify shock signals from the driven section of the main shock tube after having fired the trigger valve. The shock signals from amplifiers were transmitted to the DAQ devices through the terminal block, see figure 4-2.

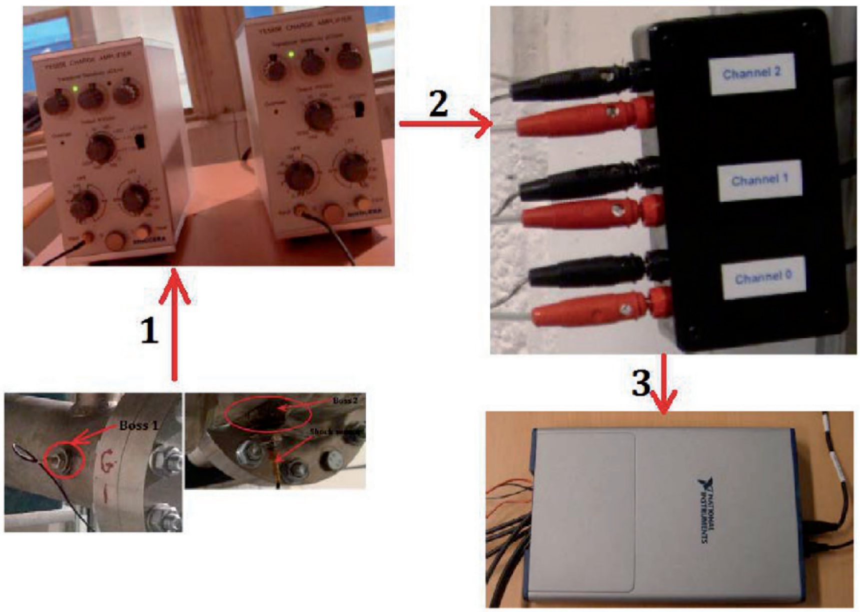



Figure 4-3: Show Sensors at Boss1 and Boss2; Charge amplifier; Terminal Block; DAQ Device

### Strain Gauges

Three strain gauges were bounded at the center of the testing specimen as shown in figure 2-30. The testing specimen was then mounted on the front face of T-section of the main shock tube by using the flange's end cover, bolts and nuts, see figure 4-4. Three signals from wires (white, green, red) were displayed on the personal computer for sensors pre-checking by using LabVIEW® Signal Express software program through Wheatstone bridge circuit and DAQ device, see figure 4-4. This process helped to avoid some errors caused by connections (noises) before running the experiment.

Three wires from the mounted specimen were connected to the Wheatstone bridge according to the marked of channels and color codes to form a complete set of the bridge circuit as shown in figure 4-4. The Wheatstone bridge circuit was then connected to the input and output channels of DAQ device. The output channel (A01) from DAQ device was used to supply 10.07V DC to the Wheatstone bridge circuit. From this 10.07V DC supplied to the bridge circuit, 7.76V DC was use as excitation voltage to the circuit.

The DAQ input channels (AI4 AI 12, AI5 AI 13, AI6, AI 14) were used to receive signals from the Wheatstone bridge circuit for the three strain gauges.

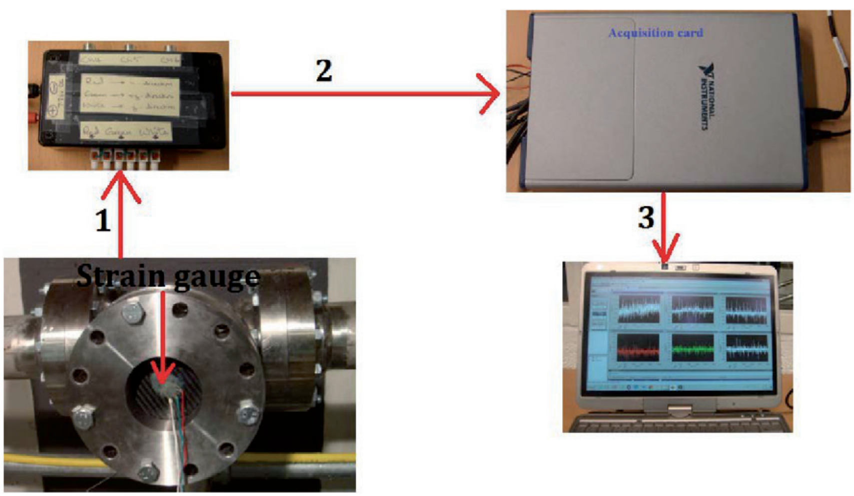



Figure 4-4: shows Mounted strain gauge; Wheatstone bridge; .DAQ device; PC

DAQ device was used to convert Analogy signals from the strain gauges, static and dynamic sensors to the digital signals, so that, the computer can translate. The application software programs were implemented on the computer by using LabVIEW application software platform and DAQmx driver software which installed in the computer .The implemented software programs were used to aid on capturing and recording the experimental data from sensors and strain gauges. These data were collected and saved to the text file in .lvm format after having fired the trigger valve.

The Calibration and data analysis application software program was setup on the computer. This software was used to convert the voltage units of the recorded data to the actual units (Pressure units and strain units)

## 4.4 Operation details of Remote Control Switch (Switch box)

This switch box consists of three switches to activate filling solenoid valve, relief solenoid valve, and trigger valve, see figure 4-5. The filling switch was used to open the filling solenoid valve on the control panel so that to allow the pressurized air to flow on the driven section of the main shock tube.

The relief switch was used to open the relief solenoid valve so that to release the pressurized air from the driver section of shock tube to the atmospheric pressure after having finished the experiment.

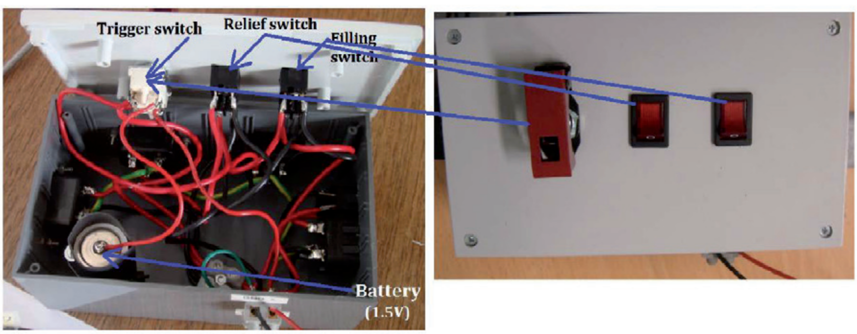



Figure 4-5: Remote control switch (switch box)

The trigger switch was used to open the trigger valve on the shock tube so that to allow the pressurized air from the driver section to flow on the driven section of the shock tube. This switch was also used to supply 1.5V DC to the DAQ device, since this switch has double functions. The DC voltage of 1.5V was supplied by a battery which is located within the remote control switch, see figure 4-5. This voltage of 1.5V DC was used to trigger DAQ device so that, the device started to record experimental data from sensors and strain gauges within 220ms.

## 4.5 Safety and checklists for equipment in the standard operational procedure

The checklists detailed below outline the standard operating procedures and efficient operation of shock tube. Failure to comply with these procedures could result in serious injury and several damages to equipment.

### 4.5.1 Safety Checklist for the main control panel of shock tube

- Check the main control panel to see if the following valves are in the correct position:-
- V1 closed, V2 closed, V3 closed and V4 closed (see Figure 4-1)
- Check that, the pressure gauges P1 and P2 are pointed to the zero position.
- Check SV1 and SV2 if they are in order for the safety purpose.
- Check AC2DC Converter, if it has connected properly to the static pressure sensor and it has powered by 230V AC (see Figure 4-1)
- Check if sensor1 has well connected to the data acquisition device (DAQ device) through the terminal block. (see Appendix A2)
- Check the solenoid valves by switching on and off from control panel; these include filling valve, relief valve and trigger valve. The correct function is judged by clicked sound produced when engaged. Once this test has completed ensure all solenoid valves have turned off.

### 4.5.2 Procedures for mounting the testing specimen to the T-section

- Remove the bolts which hold the flange and specimen on front of T-section.
- Place the specimen and flange to the T-section and then, replace and tight the bolts by two socket wrenches whiles keeping the three wires of strain gauges attached to the testing specimen.
- Connect three wires from testing specimen at T-section to the Wheatstone bridge and then to acquisition device (DAQ) for the purpose of collection the strain data to the PC (see figure 4-4)

### 4.5.3 Checklist for the charge amplifiers

- Check if both two amplifiers have connected well to the electrical power rated 230V AC (Appendix A2).

- Check if both two sensors (piezoelectric pressure transducers at Boss1 and at Boss2) in the driven section of main shock tube have connected well to the individual amplifier (see Appendix A2).
- Check if the cable from each amplifier has connected well to the data acquisition device (DAQ device) through the terminal block (see Appendix A2).

### 4.5.4 Procedures for filling water on the driven section before experiment

- Remove the bolts which hold the flange at the end of the driven section, see figure 4-6.
- Prepare thin plastic materials (such as cling film) with the size of flange see, figure 4-6.
- Close the open end of the driven section by using thin plastic material (cling film), see figure 4-6.
- Open valve V5 (see figure 4-1) to ensure that air is not trapped inside the driven section of the shock tube. In case V5 has left closed during filling process, thin plastic material (cling film) holding the water will burst.
- Fill driven section with water while valves V7 (see figure 4-1) has opened while V6 (see figure 4-1) has kept closed
- Allow overflowing of water from valve V5 (see figure 4-1) to remove any air bubbles in the driven section,
- Valve V6 (see figure 4-1) can also be used to remove any air bubbles in the driven section.

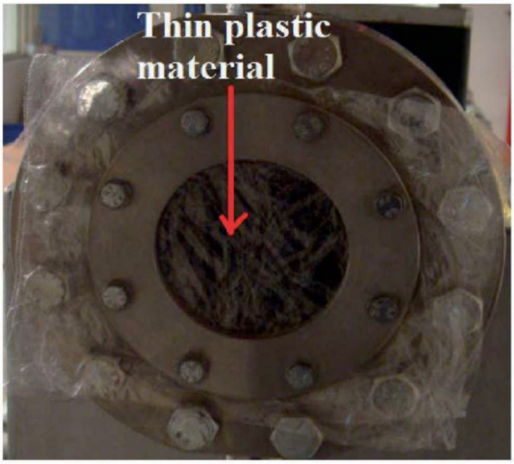



Figure 4-6 Open end of driven section

4.5.5 Checklist for preparation of remote control panel

- Check if the main switch has connected to the 230V AC power supply.
- Check if the cables of filling valve, relief valve and trigger valve located on the main control panel and are connected to the remote main switch.
- Check if data acquisition device (DAQ device) has connected well to the PC and to the remote control switch.
- Check if the power button on the remote control switch has turned on while remote control switch being operated.
- Trigger button on remote control switch generates electric signal to interfere with the trigger valve and DAQ device. Caution must be taken before running final tests by double checking the DAQ system.

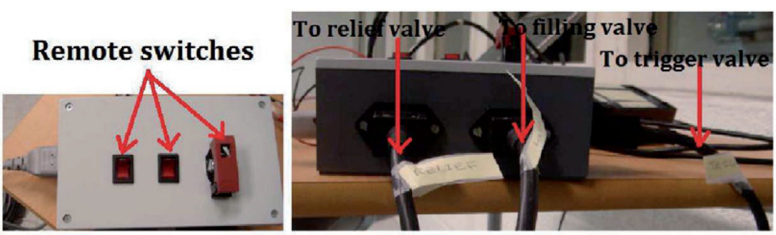



Figure 4-7: Main remote switch

4.5.6 The Procedure for the preparation of DAQ system

- Ensure the LabVIEW application software program, LabVIEW® Signal Express software and DAQ (NI-DAQmx) driver software program have installed in the PC.
- Connect NI USB-6351 X Series Data Acquisition to the Remote Control switch.
- Connect three cables from block terminal and three from Wheatstone bridge circuit to the NI USB-6351 X Series Data Acquisition by consideration of numbers of input/output channels.
- Connect NI USB-6351 X Series Data Acquisition to the PC using USB cable.

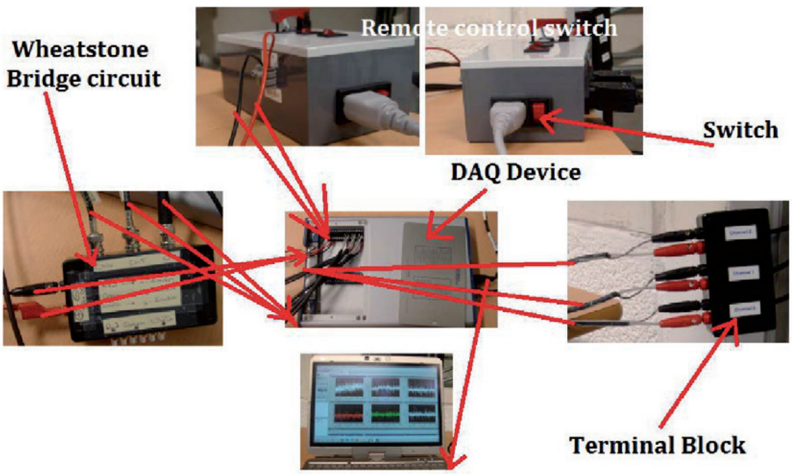



Figure 4-8: Shows the connections of DAQ System

4.5.7 SOPs for generating shock wave data

- Open valve V2 by turning anticlockwise the valve's handle (see figure 4-1).
- Open throttle valve V1 by turning anticlockwise the valve's handle. The pressure on P1 will rise to the cylinder pressure (see figure 4-1). This pressure value supposed to be less than 300bar.
- Before following further steps, make sure all wirings have correctly connected, within the shock tube room.
- Open V4 by turning anticlockwise the valve's handle (see figure 4-1).
- Open throttle valve V3 by turning anticlockwise the valve's handle (see figure 4-1). The pressure gauge P2 will rise to the desired pressure (< 100bar).

- Leave the room of the shock tube, and then close the door for the safety purpose
- Turn on the remote switch for filling valve which is located on the control panel
- Watch the pressure gauges P1 and P2. P1 drops while P2 starts to rise during the filling process.
- The filling is completed once P1 returns to cylinder pressure and P2 shows the shock tube pressure. Both P1 and P2 show steady value. At this stage, turn off the switch for the filling valve. The pressure can be also monitored using static pressure sensor placed at filling side using signal transmitted via DAQ system to PC. On this case, when the driver section of the shock tube has already charged by pressurized air, however this pressure can be discharged also by using the relief valve.
- Ensure DAQ system is on and all wires have connected properly.
- Ensure LABVIEW® Signal Express program is running on the PC.
- Ensure Calibration and Data analysis software program has setup in the PC.
- Once all above steps are checked then proceed with the final steps. Precaution should be taken before triggering, since this will generate loud sound. It is recommended to put on earplugs.
- Press the trigger button on the remote main switch to engage trigger valve, and then turn it off immediately.
- See the response of pressure sensors in the LabVIEW program to validate the functionality.

### 4.6 The operations of Software and Data analysis programs

Two software application programs were installed on the PC. These application programs are NI LabVIEW® graphical program, and NI LabVIEW® Signal Express program. The NI LabVIEW graphical program was used to implement two programs on the Block diagram and display on the Front Panel of LabVIEW®. The LabVIEW® Signal Express program was used to implement the simple software program for sensors pre-checks. Another software program was implemented by using Python programming language to aid the conversion of data units from Voltage units to the pressure and strain gauges' units. The application software from Python programming language was setup to the computer as Calibration and Data analysis software program. Figure 4-13 shows the Sequence of Hardware and Application software programs on the shock tube setup

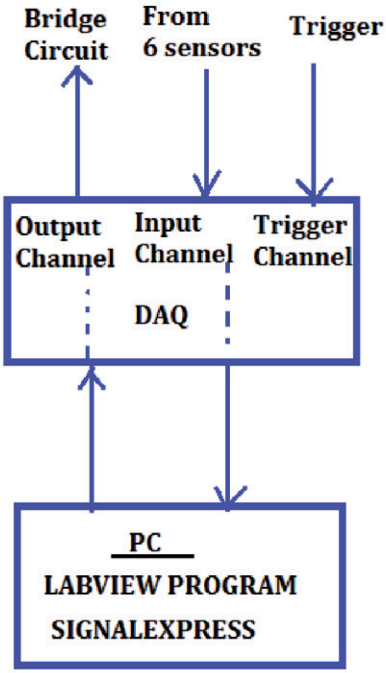



Figure 4-9: Sequence of Hardware and Application software programs

### 4.6.1 Data Acquisition Program

The data acquisition program was developed for recording experimental data in a consistent and easily analyzed format. The software program captures, records, and saves the important experimental data, and display those recorded data to the graphical indicators .This action was done completely within 220ms after having fired the trigger valve. The code shown on the block diagram (see figure 4-14) is the one which was implemented on the LabVIEW application program platform for data acquisition program. The implemented program was used also to display recorded data in graphs and to write those recorded data in the text files, see figure 4-14 below.

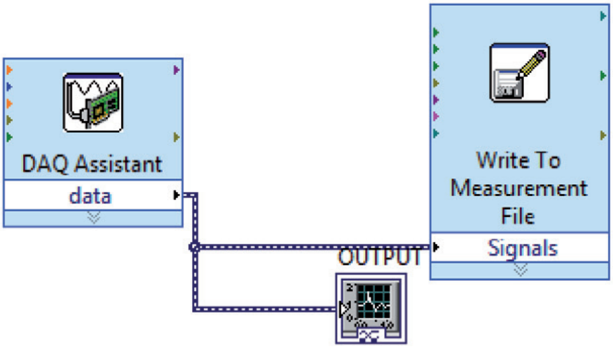



Figure 4-10: The code on the Block diagram for collecting data, recording, saving and displaying on graph indicator.

The following steps should be considered during running of LabVIEW program.

- Install NI LabVIEW® graphical program software (Version of 2010 or later) in the PC
- After having finished the installation of NI LabVIEW® graphical program software to the PC, run the program by double clicking its icon, and then select Blank VI, see figure 4-15 below.
- After having selected Blank VI on the LabVIEW, two windows (Front panel and Block diagram) will appear on the computer screen, (see figure 4-16).
- Create simple code by using Block diagram, see figure 4-14. This code includes the process of collecting, recording, saving and displaying data.
- Compile the program, and check any syntax errors.
- Test the program by closing and opening the remote switch of trigger valve while all equipment has connected well to shock tube.
- Check if data from sensors and strain gauges have captured and recorded by program. This will be shown on the graph indicator to the Front Panel of LabVIEW program and to the text file which is in .lvm format, see figure 4-17.

The software for writing data signals to the Measurement File

The "Write Measurement File" function in the File I/O palette in LabVIEW was used to implement program software for writing data signals to the text files, see figure 4-14. The LVM data file format was used instead of TDMS file format which gives binary files. LVM file format is shown on figure 4-16 below.

The program for sending Voltage Signal from PC to DAQ device

The application program software was implemented on the NI LabVIEW software program to aid on sending voltage signal from PC (10.07V DC approx.) to the DAQ device. The code of this program is shown on figure 4-15. This voltage (7.76V DC of 10.07V DC) was then used on the Bridge circuit as excitation voltage through the output channel of DAQ device, see figure 4-15


Figure 4-11: The code on the Block diagram for DC signal

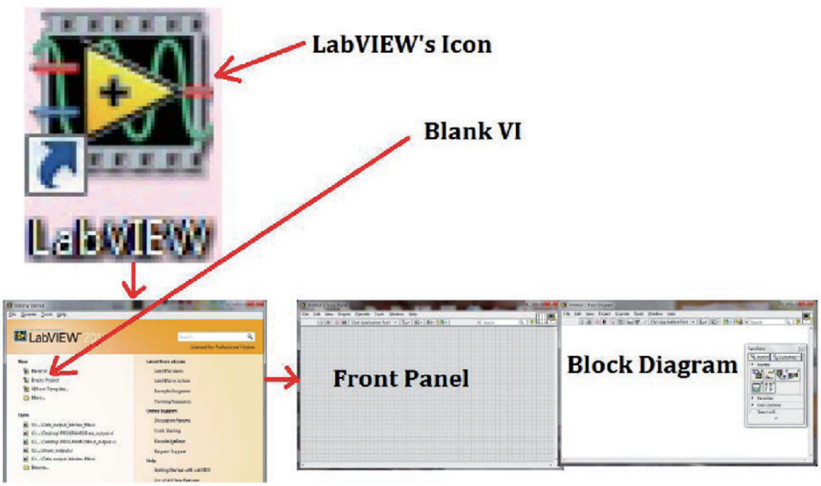



Figure 4-12: Sequence of starting the LabVIEW application software program

Aluminium Plate.lvm - Notepad

File Edit Format View Help

| | | | | | | |
|---|---|---|---|---|---|---|
| 0.000000 | 6.365960 | -0.011085 | -0.015595 | 0.001803 | 0.002448 | 0.002126 |
| 0.000100 | 6.368216 | -0.011085 | -0.016884 | 0.002126 | 0.001803 | 0.002770 |
| 0.000200 | 6.374338 | -0.010762 | -0.015273 | 0.001803 | 0.002770 | 0.002448 |
| 0.000300 | 6.376271 | -0.010118 | -0.013984 | 0.001803 | 0.002126 | 0.002770 |
| 0.000400 | 6.379493 | -0.012696 | -0.017851 | 0.001803 | 0.002126 | 0.002126 |
| 0.000500 | 6.383037 | -0.010118 | -0.019140 | 0.002770 | 0.002126 | 0.002126 |
| 0.000600 | 6.390448 | -0.010762 | -0.016240 | 0.001803 | 0.003092 | 0.002448 |
| 0.000700 | 6.558642 | -0.011085 | -0.016562 | 0.001803 | 0.002448 | 0.002448 |
| 0.000800 | 6.885363 | -0.010440 | -0.016562 | 0.001803 | 0.002770 | 0.002126 |
| 0.000900 | 6.764534 | -0.010762 | -0.014951 | 0.001481 | 0.001481 | 0.002770 |
| 0.001000 | 6.619539 | -0.011407 | -0.015273 | 0.001803 | 0.002126 | 0.002126 |
| 0.001100 | 6.515466 | -0.011729 | -0.016240 | 0.001159 | 0.002448 | 0.002126 |
| 0.001200 | 6.452957 | -0.012051 | -0.016884 | 0.001481 | 0.002448 | 0.002126 |
| 0.001300 | 6.410747 | -0.010762 | -0.015918 | 0.002126 | 0.002126 | 0.002126 |
| 0.001400 | 6.387871 | -0.011729 | -0.015273 | 0.001803 | 0.002126 | 0.002448 |
| 0.001500 | 6.373371 | -0.010118 | -0.017206 | 0.002126 | 0.002126 | 0.002126 |
| 0.001600 | 6.364671 | -0.009151 | -0.018173 | 0.001159 | 0.002770 | 0.003092 |
| 0.001700 | 6.360161 | -0.009796 | -0.017529 | 0.001159 | 0.002126 | 0.002770 |
| 0.001800 | 6.358227 | -0.009796 | -0.016884 | 0.001481 | 0.002448 | 0.002126 |
| 0.001900 | 6.357583 | -0.011729 | -0.017206 | 0.001159 | 0.002126 | 0.002770 |
| 0.002000 | 6.359838 | -0.011407 | -0.016562 | 0.002126 | 0.002770 | 0.002126 |
| 0.002100 | 6.360161 | -0.010440 | -0.012696 | 0.001803 | 0.002448 | 0.002126 |
| 0.002200 | 6.362738 | -0.011729 | -0.017206 | 0.001803 | 0.001803 | 0.002126 |
| 0.002300 | 6.364027 | -0.016884 | -0.017851 | 0.001803 | 0.002448 | 0.003092 |
| 0.002400 | 6.366605 | -0.011407 | -0.014307 | 0.001803 | 0.002126 | 0.002448 |
| 0.002500 | 6.369182 | -0.008829 | -0.016562 | 0.001803 | 0.002448 | 0.002448 |
| 0.002600 | 6.372404 | -0.010762 | -0.013340 | 0.003092 | 0.002126 | 0.002448 |
| 0.002700 | 6.376915 | -0.010118 | -0.019784 | 0.002126 | 0.002126 | 0.001803 |
| 0.002800 | 6.384326 | -0.009474 | -0.015918 | 0.002126 | 0.002448 | 0.002770 |
| 0.002900 | 6.384326 | -0.008185 | -0.016884 | 0.001481 | 0.002770 | 0.002448 |
| 0.003000 | 6.389804 | -0.012373 | -0.015595 | 0.002126 | 0.002126 | 0.002770 |
| 0.003100 | 6.599562 | -0.011729 | -0.017851 | 0.001803 | 0.002448 | 0.002448 |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 |

Table 4 -1: Shows the recorded data of Aluminium plate with LVM text file format; first column shows the time, second column shows the static pressure sensor, third column shows pressure transducer after trigger valve, fourth column shows pressure transducer at T-section, Last three column show strain gauge

4.6.2 The Procedure of using Calibration and Data analysis software

The purpose of the program was to convert the recorded data units of pressure sensors and strain gauges from the voltage units to the actual pressure and strain units. The following below was the procedure of using calibration and data analysis software program.

- Run the DataReader0.8a.exe.
- Insert a file of type lvm. format
- Once the file has inserted and opened, the graphs as shown on figure 4-18 will be displayed.
- Press 1-3 pressure buttons, the pressure (KPa) over time (ms) graph will be displayed which will show the variation of pressure from sensor 1 to 3.
- Press 1-3 strain buttons; this will display the variation of recorded strain over time graph.

There are two also extra buttons for opening and saving files. The "Open file button" is used for opening a new lvm-file and "Save file button" is used for saving the current state of the graph into a folder's name data file.

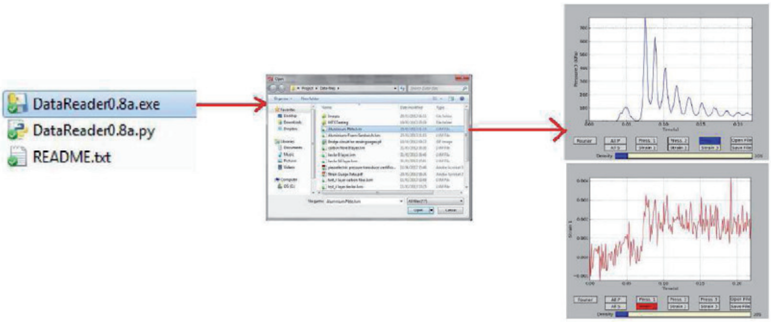



Figure 4-13: Shows the sequence of using the unit converter software

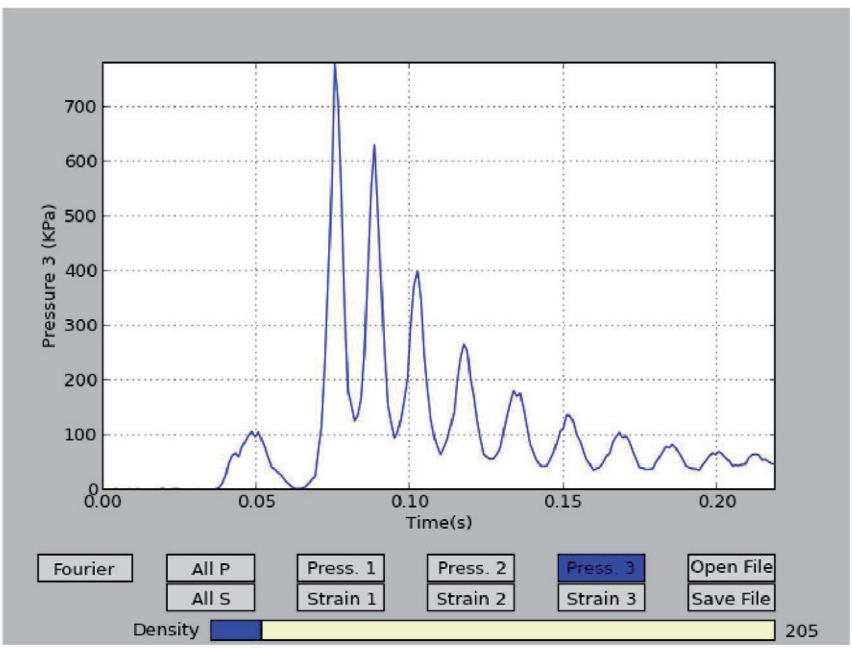



Figure 4-14: Shows the graph for pressure (KPa) against time(s)

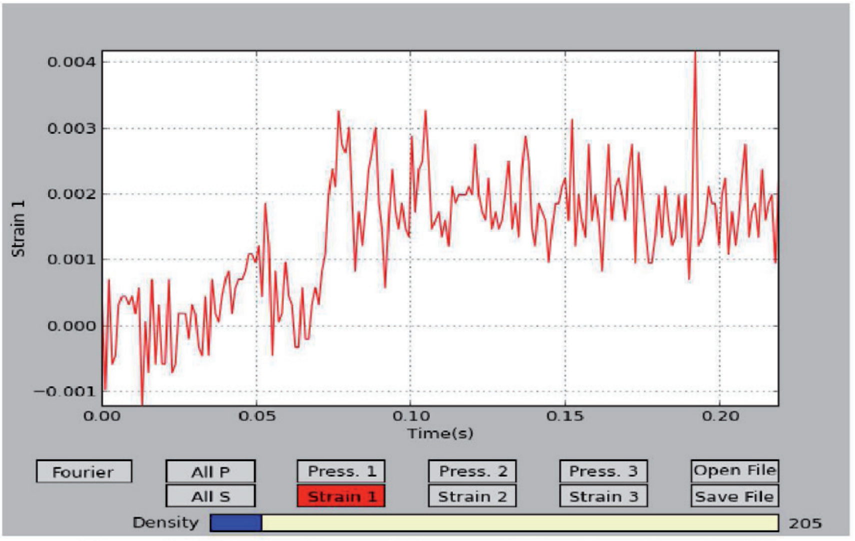



Figure 4-15: Shows the graph for recorded strain against time(s)

# Chapter 5: Conclusions and future work

## 5.1 Conclusions

Chapter one of this reports has covered the following sections:

- The historical background of the shock tube testing facility.
- The purpose of the researches for understanding the failure of composite shell structures under dynamic shock loads and their interactions. These researches led to the introduction of the modern shock tube testing facility to aid the testing of composite materials.
- The introduction to strain gauges, Wheatstone bridge circuit, LabVIEW application software program, DAQ driver software (DAQmx), LabVIEW® Signal Express program and physical and virtual channels.
- The overview of the report has also explained in this chapter

Chapter 2 has covered the list of the equipment which are connected together to setup the shock tube. The chapter has included features and specifications of the equipment in the shock tube.

Chapter 3 has covered the safety in the working place, limitation of usage and risk assessment. The following sections were also included in this chapter.

- The important of safety in the working place
- Accidents in the working place and their consequences
- The contribution to safety by workers in the working place
- Risk management. The key to cost containment. This includes:
    - Developing and refining safety management system
    - Managing safe operation and maintenance
    - Creating a safety culture
    - Training and familiarization
    - Motivation and leadership

- Routine operation of the working place
- Record keeping which is an important of the safety management system for routine operation and essential for auditing purposes.

- Risk Assessment, which is an essential aspect of safety management. This section includes also:
  - How to manage a successful risk assessment
  - The importance of risk assessment
  - The ways of doing the risk assessment

- The limitation for the usage of equipment in the working place
- The protection principles, which are defined as the way of excluding the equipment and component as the ignition, source in the working place.
- Personal Protective Equipment (PPE). This section has explained that, the PPE requires the employers to certify in writing that, they have performed the assessment, and verify in writing that:
  - Employees have been trained on and understand the necessary use
  - Limitations and proper care and
  - Maintenance of personal protective equipment.

- Electrical safety training requirements. This section has explained that, the workers near energized, or potentially energized electrical circuitry of fifty (50)-volts to ground or greater, shall be trained in energized electrical safe work practices and procedures, and re-trained as necessary.
- The requirements apply to the portable electrical equipment and extension codes.
- The important principles of working on de-energized equipment.
- The guidelines relating to the safety requirements during the operation in the workplace
- Responsibilities of the occupational safety and Health Administration (OSHA) to the working place.
- The explanation relating to the test, verification, approval, and certification of the equipment in the shock wave tube testing facility. This section has explained the equipment, which was used to setup the shock tube and the certificates offered to approve that the equipment qualified.
- Chapter 4 has covered the explanations of the Standard Operational Procedures (SOPs) for using shock tube testing facility. This includes the following sections.
- The descriptions of general operation of shock wave tube.

- The descriptions of the instrumentation (static sensor, dynamic sensors, and strain gauges).
- The operation details of the remote control switch (switch box).
- Safety and checklists for the equipment in the standard operational procedure. This includes:
  - Safety checklist for the main control panel of shock tube
  - Procedures for mounting the testing specimen to the T-section
  - Checklists for the charge amplifiers
  - Procedures for filling water in the driven section before experiment
  - Checklist for preparation of remote control panel
  - The procedure for the preparation of DAQ system
  - SOPs showing all steps for generating shock wave data

- The operations of software and data analysis programs which includes:
  - Data acquisition program.
  - The procedure of using Calibration and Data analysis software.

## 5.2 Future Work

The suggestions for the future work are as follows:

- To introduce the shock tube testing facility to the petroleum industries and ship companies as a useful device for testing the composite materials which will be used on the piping systems to transfer gases, petroleum products, and other fluids with high pressure.
- To introduce the shock tube testing facility to the different universities and colleges as a training device for engineering students. This is because; the facility has consisted with fluid mechanics, electronics and electrical devices as a part of physics. The facility has software programs for the data analysis as a part of computer science.
- To plan the best design for the experimental rooms. The idea behind is to have two room, the first one for the shock tube and main control panel and the second one is for the remote control. The remote control room will be separated by sight glass with the room for the shock tube. The remote control room will be equipped with DAQ system devices and switches.

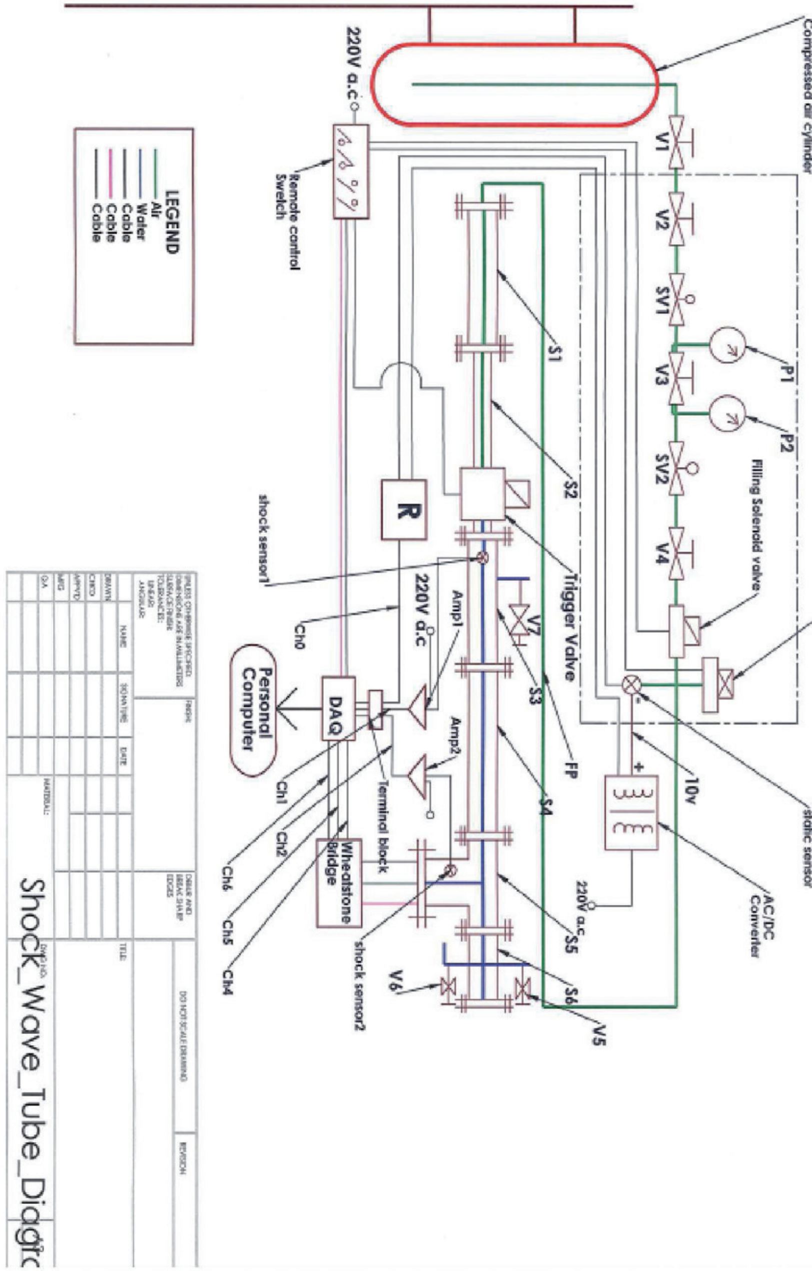
- To establish the safety requirements in the experimental rooms by introducing the written safety procedures.
- The Personal Protective Equipment (PPE) refers to protective clothing, helmets, or other equipment designed to protect the wearer's body from injury should be placed in the working place for the safety purpose.

## Appendix A: Equipment List and Schematics

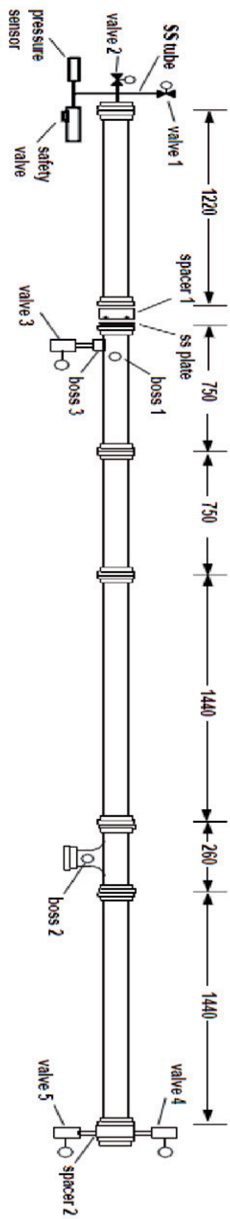
### A1. Equipment List

1. Compressed air cylinder
2. Cylinder Valve (V1)
3. Flexible hose pipes
4. Fittings and Connections
5. Manually Operated Valves (V2 and V4)
6. Pressure Reducing Regulator Valve (V3)
7. Safety Relief Valves (SV1 and SV2)
8. Electrically Operated Valves (Relief, Filling, and Trigger Solenoid Valves)
9. Pressure Gauges (P1 and P2)
10. Static Pressure Sensor (Compact Pressure Transducer)
11. Stainless Steel Main shock tube (Driver and Driven Section)
12. Flanges and O-Rings
13. Water Inlet and Outlet Valve (V7 and V6 respectively)
14. Dynamic Pressure Sensors (Shock sensors at Boss1 and Boss2)
15. Strain gauges (Mounted on the testing specimen at T-Section of Main Shock Tube)
16. Water Valve for releasing the remaining water air bubbles in the Driven section (V5)
17. Rupture face at the end of the driven section of the main shock tube.
18. Main Shock Tube supports
19. Charge Amplifiers Amp1 and Amp2)
20. Wheatstone bridge
21. Terminal Block
22. Remote control switch
23. DAQ device
24. Personal Computer
25. Cable and Accessories
26. Electric Extension lead

## A2. Schematic Shock Tube Diagram



<u>A3. Shock Tube Fabrication details diagram</u>



## A4. General Specifications details of the main shock tube

The following is a proposed shock tube design for use with driver pressures of up to 100 barg.

The design is based around the use of water in the driven section, although use of the tube is not restricted to this application.

Reference is made to Figure 1 in describing the detailed components.

**BASIC SHOCK TUBE**

The maximum operating pressure for experimental work is specified as 100 barg. The proposed tube material is schedule 80 seamless pipe made in 316 stainless steel and specified as 3" nominal bore. The following characterises the main pipe parameters :

| | |
|---|---|
| outside diameter | = 88.9 mm |
| wall thickness | = 7.62 mm |
| yield strength | = 248 MPa |
| working pressure rating | = 163 bar |
| internal diameter | = 73.7 mm |
| weight | = 15.5 kg/m length |

For operation at 100 bar pressure, the hoop stress corresponds to 58 MPa, which is 20% of the yield strength of the material. This margin of safety is seen as important in view of the possibility of over-pressurising from available pressurising sources, such as gas bottles (200 bar).

The tube is constructed from a number of lengths, which are designed to be interchangeable and included is a measurement section in the form of a Tee, where loaded components can be attached. This Tee section can be moved to different locations to allow for different load exposure durations to be applied.

Key constructional details are associated with the joining of the tube sections. These joints must ensure that strength requirements are met and that continuity of the bore is maintained without mis-alignment. The tube sections are joined by flanges, which meet these requirements and which conform to the current Pressure Equipment Directive 97/23/EC. These flanges are around 190 mm in diameter, are held by 6 bolts and sealed with O rings on the faces.

Referring to Figure 1, the left hand section of the tube is the driver and has a blind flange at its left hand end. The opposite end of this section is terminated in 3 elements, (a) a bursting disc, (b) a 40m thick spacer and (c) a restriction plate with an orifice. Each of these elements is located within the inner pitch circle of the flange bolts and sealed with O rings on their faces.
The bursting disc is chosen in material and thickness to meet the operating pressure of the test and forms the initial seal with the driver. The spacer allows the petals of the disc to displace on bursting and the restriction plate controls the rate of flow of air into the downstream section and hence the downstream pressures.

# A5. Features of Sandwich style ball valves

# S Series

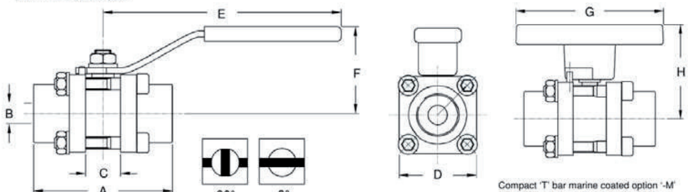

**General Information**

## Sandwich style ball valve 1,000 psi to 3,000psi

The bolt together style or 'S' Series valve offers flexibility and interchangeability. It is manufactured with the choice of threaded, socket or butt weld ends for installing the valve into the pipeline. Once installed, it is easily maintained by removal of the centre section for renewal of the seats and seals prolonging the valve life. Being a 'Bolt together' design it is readily converted to actuator control. To ease maintenance, the centre section is sold separately, as are the maintenance / repair kits.

## Design Features

*Bi-directional floating ball design to ensure leak-proof shut-off on pressure or vacuum.*
*Anti-blow-out internally loaded stem for safety.*
*Replaceable centre section for economy.*
*Can be actuated.*
*Positive 90° action-position indication.*
*Available in 3 pressure ranges S = 1,000 psi / RS = 2,000 psi / HS = 3,000 psi.*
*Full material traceability.*
*Repair kits available to prolong valve life.*
*Materials of construction can be supplied to meet the requirements of NACE MR-01-75.*




Stainless steel handle as standard

Compact 'T' bar marine coated option '-M'
Stainless steel 'T' bar option '-MS'

## Part Numbers

| St/St Part No. | Connections Size | A | B (Bore) | C | D | E | F | G | H | CV | KV | Weight (kgs) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S2NS | 1/4" NPT | 68 | 10 | 17.4 | 38 | 115 | 37 | 75 | 47 | 4.2 | 3.6 | 0.4 |
| S3NS | 3/8" NPT | 68 | 10 | 17.4 | 38 | 115 | 37 | 75 | 47 | 4.4 | 3.8 | 0.4 |
| S4NS | 1/2" NPT | 68 | 10 | 17.4 | 38 | 115 | 37 | 75 | 47 | 4.5 | 3.9 | 0.4 |
| S6NS | 3/4" NPT | 73 | 13 | 22.2 | 40 | 115 | 38 | 75 | 45 | 9.5 | 8.2 | 0.65 |
| S8NS | 1" NPT | 102 | 19 | 32.5 | 50 | 150 | 44 | 75 | 52 | 19 | 16.4 | 1.0 |
| S10NS | 1 1/4" NPT | 103 | 25 | 38.6 | 60 | 150 | 55 | 75 | 64 | 30 | 26 | 1.50 |
| S12NS | 1 1/2" NPT | 118 | 32 | 47.6 | 76 | 170 | 90 | - | - | 49 | 42.4 | 2.70 |
| S16NS | 2" NPT | 130 | 38 | 60.3 | 83 | 170 | 94 | - | - | 70 | 60.5 | 3.25 |
| S20NS | 2 1/2" NPT | 150 | 50 | 69.9 | 114 | 215 | 83 | - | - | 119 | 103 | 6.00 |

Dims are in mm (Appx)

For 3,000 psi version add 'H' i.e. HS4NS
For Socket Weld Substitute 'S' for 'P' i.e. S16SS.
For Butt Weld Substitute 'B' for 'P' i.e. S16BS.
For Centre Section Only Substitute 'O' for 'P' i.e. S16OS.
For 2,000 psi version add "R" i.e. RS4NS
Seat materials: 1000psi = PTFE - 2000psi = RTFE - 3000psi = Acetal    Seal materials: Body = PTFE - Stem = RTFE
Note: 1 1/4" sizes and above are rated 2,000 psi max.

See technical section for important additional valve data.



Alco Valves
Industrial Valve Manufacturers
Europe (UK)
Tel : 01484 710511 Fax 01484 713009
International : ++ 44 1484 710511
USA & Canada
Tel : ++ (1) 519 767 6655 Fax ++ (1) 519 767 6740
www.alco-valves.com

REF: AVCAT2005019
REV: 01

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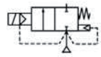
## A6. Details for the features of the solenoid valves

# SOLENOID VALVES

high pressure, pilot operated
for CNG applications
3/8 to 1/2

NC 

**2/2**
Series
**291**

### FEATURES

- The normally closed high pressure valves are especially designed to meet the particular heavy duty requirements of CNG applications
- Stainless steel body material to achieve a compact and reliable design
- The high quality PEEK piston guarantees a long operating life and a large temperature range
- Valves can withstand a burst pressure beyond 1400 bar
- Explosion proof operator, intended for use in potentially explosive areas, according to Directive ATEX 94/9/EC
- Easy electrical installation by means of the moulded-in supply cable, standard length 2 meter
- All components satisfy all relevant EC directives

### GENERAL

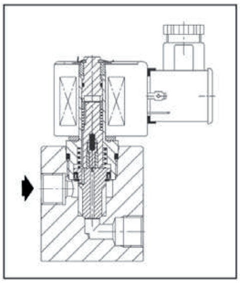
**Differential pressure** 10 - 350 bar [1 bar = 100kPa]
**Ambient temperature range** -40 to +70°C

| fluid (*) | temperature range (TS) | seal materials (*) |
|---|---|---|
| CNG | -40 to +70°C | FPM (fluorelastomer)<br>High-grade PTFE / 302 Stainless steel |

### MATERIALS IN CONTACT WITH FLUID

**(*) Ensure that the compatibility of the fluids in contact with the materials is verified**

| | |
|---|---|
| **Body** | 303 Stainless steel |
| **Core** | Aluminium bronze |
| **Piston** | PEEK |
| **Core and plugnut** | 430F Stainless steel |
| **Core spring** | 301 Stainless steel |
| **Sealing (U-cup)** | FPM<br>High-grade PTFE / 302 Stainless steel |
| **O-ring** | FPM |



### ELECTRICAL CHARACTERISTICS

**Standard voltages:**
DC (=): 24V - 48V
AC (~): 24V - 48V - 115V - 230V / 50 Hz

### SAFETY CODE

Ex II 2G EEx m II T4 (gas)
Ex II 2G EEx em II T3 (gas)

AC (~) Solenoids ((WS)EM operator only)

| power level (watt) | insulation class | maximum ambient [1] temp. "T" classification | | | |
|---|---|---|---|---|---|
| | | T6 (G) | T5 (G) | T4 (G) | T3 (G) |
| 10,0 | F | - | - | - | 40°C |

DC (=) Solenoids ((WS)EM and PV operator)

| power level (watt) | insulation class | maximum ambient [1] temp. "T" classification | | | |
|---|---|---|---|---|---|
| | | T6 (G) | T5 (G) | T4 (G) | T3 (G) |
| 11,2 | F | - | - | 65°C | 40°C |

[1] Make sure that the selected ambient temperature does not exceed the allowable valve temperature characteristics as specified on the appropriate valve catalogue sheets.

### SPECIFICATIONS

| pipe size | orifice size | flow coefficient Kv | | operating pressure differential (bar) | | catalogue number | |
|---|---|---|---|---|---|---|---|
| | | | | min. | max. (PS) CNG | | |
| ❖ | (mm) | (m³/h) | (l/min) | | ~/= | DC only | AC & DC |
| **NC - Normally closed** | | | | | | | |
| 3/8 | 8 | 0,96 | 16 | 10 | 350 | PV ❖291A410 | (WS)EM ❖291A410 |
| 1/2 | 12 | 2,30 | 38 | 10 | 350 | PV ❖291A420 | (WS)EM ❖291A420 |

❖ Select **G** for ISO 228/1 or **C** for SAE

2007/R0

# A7. Specification details for High Pressure Transducer

Gems Sensors & Controls

PRESSURE SENSORS

PRESSURE TRANSDUCERS

SPUTTERED THIN FILM

## 3100 Series Compact High Pressure OEM Pressure Transmitter

- 10 bar to 2200bar pressure ranges
- Less than 25mm long
- Choice of outputs

For OEMs that need consistent high levels of performance, reliability and stability the 3100 Series sputtered thin film units offer unbeatable price performance ratio in a small package size with all stainless steel wetted parts in the volumes required. A wide choice of electrical outputs as well as both electrical and pressure connections means the unit is suitable for most applications without modification. The compact construction of the 3100 series makes it ideal for installation where space is at a premium.

### Specifications

| | |
|---|---|
| **Input** | |
| **Pressure Range** | 0 to 10bar to 0 to 2200bar G (100 to 30,000psi) |
| **Proof Pressure** | 2 x FS (Ranges 1600 & 2200bar 1.5x) |
| **Burst Pressure** | Ranges "400bar 10 x minimum 600 & 1000b 4 x, 1600 & 2200 1.8x |
| **Fatigue Life** | Designed for more than 100,000,000 cycles |
| **Performance** | |
| **Long Term Drift** | 0.1% FS/year non cumulative |
| **Accuracy** | ±0.25% FS (Temp O/P ± 2.5%FS) |
| **Thermal Error** | ±1% typical/100°C |
| **Compensated Temperature** | -40° to 120°C (-40° to 250°F) |
| **Operable** | -40° to 125°C (-40° to 250°F) |
| **Zero Tolerance** | ±0.5% of span |
| **Span Tolerance** | ±0.5% of span |
| **Mechanical Construction** | |
| **Pressure Port** | See ordering chart |
| **Wetted Parts** | 17-4 PH Stainless Steel |
| **Electrical Connection** | See ordering chart |
| **Enclosure** | IP65 for electrical code B (with connector fitted)<br>IP67 for electrical codes E, 6, 7, 8 and 9 |
| **Vibration** | 20G, 10-2000Hg sinusuidal |
| **Shock** | Withstands free fall to IEC 68-2-32 procedure 1 |
| **Approvals** | CE |
| **Weight** | 35 gms |

### Individual Specifications

| | |
|---|---|
| **Voltage Output Units** | |
| **Output** | See ordering chart (current 4.5mA) |
| **Supply Voltage** | 2 Volts above Full Scale, to max 30 Volts |
| **Current Output Units** | |
| **Output** | 4-20mA |
| **Supply Voltage** | 10 to 30Vdc (24Vdc max for 110° and above) |
| **Max. Loop Resistance** | (Vs-10) x 50 ohms |
| **Ratiometric Output Units** | |
| **Output** | 0.5 to 4.5Vdc (3.5mA max) |
| **Supply Voltage** | 5Vdc, ± 10% |

### Electrical Connectors

AMP Superseal 1.5

DIN 43650C Industrial

DIN 72585 Bayonet

M12 Ranges

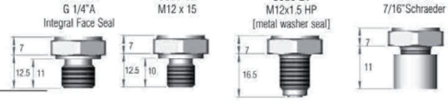
Deutsch DTD4-4P

Packard Metri-pack

**MECHANICAL FITTINGS**

Code 01 G 1/4 EXT — Code 04 7/16"-20 UNF with 37° Flare — Code 1J 7/16"-20 UNF O-Ring — Code 02 1/4"-18 NPT — Code 08 1/8"-27 NPT


Code 05 G 1/4"A Integral Face Seal — Code 0L M12 x 15 — Code 2T M12x1.5 HP [metal washer seal] — Code IG 7/16"Schraeder




Hex is 22mm [.866] Across Flats (A/F) for deep socket mounting.

Other thread forms available. Consult factory.

**NOTE: Dimensions in mm**

www.gemssensors.com

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# A8. Specification details for Piezoelectric Pressure Transducer

SINOCERA

Global Sensor Technology

## Easy Mounting Pressure Transducer

## Model CY-YD-205

**FEATURES**

- Small size and light weight
- Static calibration
- High stiffness and wide frequency range
- Pressure measurement inside pipes and explosions
- Easy mounting

**SUPPLIED WITH**

- Calibration chart
- Protective cap
- Sealing washer
- STYV-1 cable fitted with L5 connector (2m)

**STATIC PERFORMANCE**

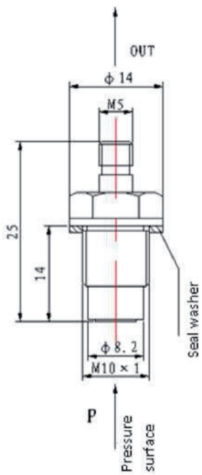
| | |
|---|---|
| Sensitivity (20°±5C ) | 350 Pc/MPa |
| Measurement range | 0 to 30MPa/0~60MPa |
| Overload | 120% of full scale |
| Non-linearity | <1% of full scale |
| Delay | <1%of full scale |
| Repeatability | <1% of full scale |
| Isolation resistance | >$10^{13}\Omega$ |
| Capacitance (1000Hz) | 7pF |

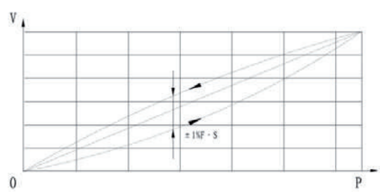
**DYNAMIC PERFORMANCE**

| | |
|---|---|
| Natural resonance | >100kHz |
| Temperature range | -40 to +150℃ |

**PHYSICAL CHARACTERISTICS**

| | |
|---|---|
| Weight | 10g |
| Case material | High strength stainless steel |
| Mounting | M10×1 |
| Sensing element | Quartz |
| Electrical connection | L5 connector |

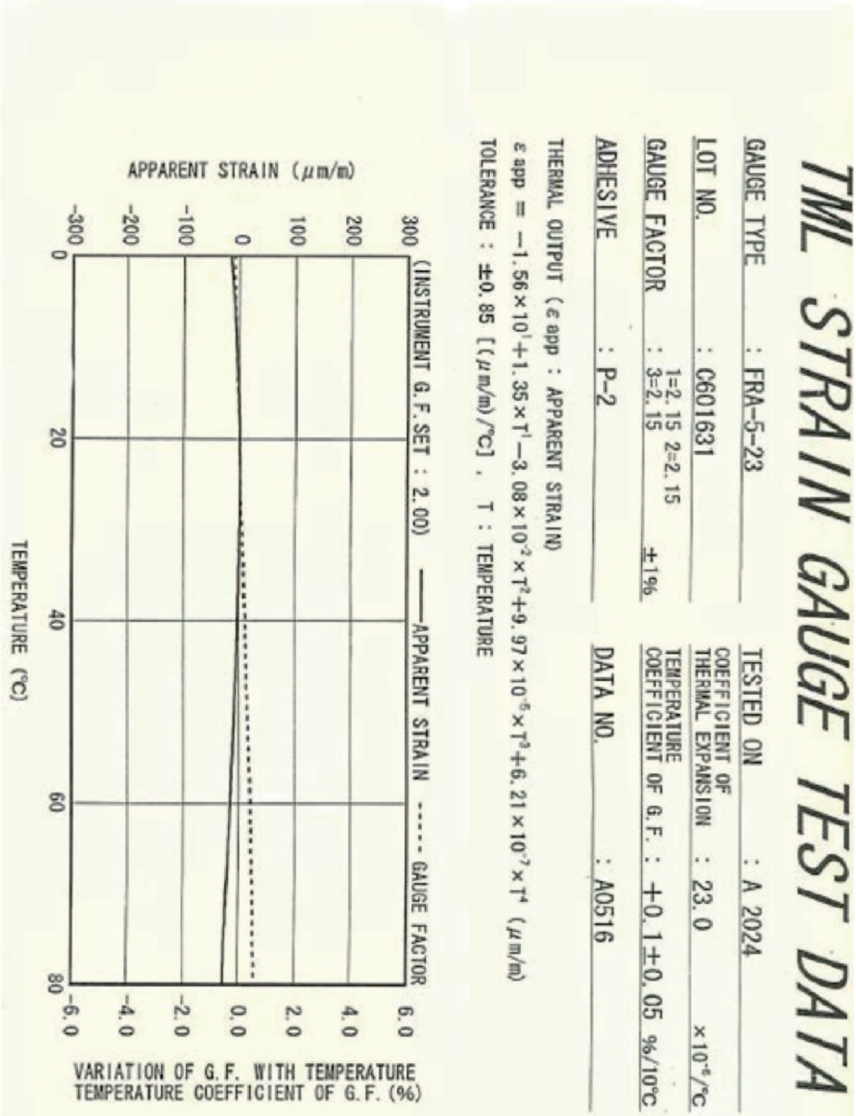



Typical static calibration chart

*Global Sensor Technology*
*Unit 1, 26 Fairholme Road, Manchester, M20 4NT, UK*
*Phone: +44 (0)161 446 4848 Fax: +44 (0)161 438 2828 www.globalsensortech.com techsupport@globalsensortech.com*

## A9. The Testing details for the strain gauge



**TML STRAIN GAUGE TEST DATA**

| | | | |
|---|---|---|---|
| GAUGE TYPE | : FRA-5-23 | TESTED ON | : A 2024 |
| LOT NO. | : C601631 | COEFFICIENT OF THERMAL EXPANSION | : 23.0 $\times 10^{-6}/^{\circ}C$ |
| GAUGE FACTOR | : 1=2.15 2=2.15 3=2.15 ±1% | TEMPERATURE COEFFICIENT OF G.F. | : +0.1±0.05 %/10°C |
| ADHESIVE | : P-2 | DATA NO. | : A0516 |

THERMAL OUTPUT ($\varepsilon$ app : APPARENT STRAIN)

$\varepsilon_{app} = -1.56\times10^{1} + 1.35\times T^{1} - 3.08\times10^{-2}\times T^{2} + 9.97\times10^{-5}\times T^{3} + 6.21\times10^{-7}\times T^{4}$ ($\mu$m/m)

TOLERANCE : ±0.85 [($\mu$m/m)/°C], T : TEMPERATURE

# A10. Specification details for YE5856 Charge Amplifier

## Charge Amplifier (wide frequency response up to 500kHz)

**Model: YE5856**

**Features:**

- The upper frequency limit up to 500kHz
- Low size, high integration
- Three decimal-system uniformization output
- Built-in multiple low pass and high pass filters
- Low noise, high precision,
- Charge and voltage inputs
- Overload Indication

**Specifications:**

| | |
|---|---|
| Input Range | Voltage: ±10VP (Max); Charge: $\pm10^6$ PC (Max) |
| Output Range | Voltage: ±10VP (Max) |
| Noise | ≤5μV (the max gain converted into the input end) |
| Overload Indication | LED on when output exceeds \|±10\| V |
| Gain | Switch Selectable 0.1, 1, 10, 100, 1000 ,10000 mV/Unit |
| Accuracy | ±1% |
| Low Pass Filter | Switch selectable 1k, 3k, 10k, 30k, 100k,500kHz (–3dB±1dB),-12dB/Oct |
| High Pass Filter | Switch selectable 0.3, 1, 3,10,30,100Hz (–3dB±1dB), –6dB/Oct |
| Temperature | Operating: 0°C to 40°C; Storage: -55°C to 85°C |
| Humidity | 95%R.H. (Max) |
| Power Supply | DC: ±18 to ±27V; AC: 220V50Hz/110V60Hz |
| Dimensions | 70mm(W)×132.5mm(H)×200mm(D) |
| Weight | 1.5kg |
| Connections | Input: L5; Output: BNC; Power Supply: 3GTJE3(AC) |
| Input Cable | Double-ended L5 STYV-1 low noise cable(2m) |
| Output Cable | Double-ended BNC 50Ω output cable(2m) |
| Power Cable | 1 |

SINOCERA PIEZOTRONICS INC.

Add：NO.1 Yuqi Street Yangzhou City P.R.China Tel:+86 514 87348717 Fax:+86 514 87348670

Http:// www.china-yec.com Email: sales@china-yec.com Support: tech@china-yec.com

A11.Table shows X Series NI-DAQmx Software Support

| Device | NI-DAQmx Version Support |
| --- | --- |
| NI PCIe/PXIe-632*x*/634*x* | NI-DAQmx 9.0 and later |
| NI PCIe/PXIe-6351/6353/6361/6363 | NI-DAQmx 9.0 and later |
| NI PXIe-6356/6358/6366/6368 | NI-DAQmx 9.0.2 and later |
| NI USB-634*x*/6351/6353/6361/6363 | NI-DAQmx 9.2 and later |
| NI USB-6356/6366 | NI-DAQmx 9.2.1 and later |

# Appendix B: Safety and Risk Assessment

## B1. Safety related to the Protection Principles

**Protection principles** BARTEC

### *Protection principles*

Protection principles are defined to exclude equipment and components as ignition sources.

Ignition sources which are caused by sparks from friction or impact or from electro-static charging have to be prevented in explosion protected equipment by selecting appropriate materials and by constructive measures, and this must be verified and confirmed by the appropriate tests.

Four protection principles can prevent equipment from becoming an ignition source. The types of protection listed as examples in the overview are discussed in a different chapter.

| Protection principles | Types of protection | Gases and Vapours | Dusts | Category | (EPL) Equipment Protection Level |
|---|---|---|---|---|---|
| Explosive mixtures can penetrate the item of equipment and be ignited. Measures are taken to ensure that the explosion cannot spread to the surrounding atmosphere. | Flameproof enclosures | ■ | – | 2 | b |
| | Powder filling | ■ | – | 2 | b |
| | Enclosed-break device | ■ | – | 3 | c |
| The item of equipment is provided with an enclosure that prevents the ingress of an explosive mixture and/or contact with sources of ignition arising from the normal. | Pressurized enclosures | ■ | ■ | 2 | b |
| | Pressurized enclosures | ■ | – | 3 | c |
| | Restricted breathing | ■ | – | 3 | c |
| | Protection by enclosure | – | ■ | 2 | b |
| | Oil immersion | ■ | – | 2 | b |
| | Liquid immersion | ■ | – | 2 | – |
| | Encapsulation | ■ | ■ | 1/2/3 | a/b/c |
| | Non-incendive component | ■ | – | 3 | c |
| | Encapsulated device | ■ | – | 3 | c |
| | Sealed device | ■ | – | 3 | c |
| | Hermetically sealed device | ■ | – | 3 | c |
| Explosive mixtures can penetrate the enclosure but can not be ignited. Sparks and temperatures capable of causing ignition must be prevented. | Increased safety | ■ | – | 2 | b |
| | Non-sparking device | ■ | – | 3 | c |
| | Protection by constructional safety | ■ | – | 2 | – |
| Explosive mixtures can penetrate the enclosure but can not be ignited. Sparks and temperatures able to cause ignition may only occur within certain limits. | Intrinsically safe | ■ | ■ | 1/2/3 | a/b/c |
| | Energy limitation | ■ | ■ | 3 | – |
| | Protection by control of ignition sources | ■ | – | 2 | – |

BARTEC applies these protection principles to its different pieces of equipment according to the application for which they are going to be used.

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# B2. Safety related to the Protection Principles

## Protection principles

BARTEC

An important precondition for all the protection principles is that parts which are in unhindered contact with the explosive atmosphere must not be able to reach non-permitted temperatures with respect to the ignition temperature of substances present in the site of installation. This means that the ignition temperature is relevant for all protection principles.

The protection principles can be equally applied to electrical and non-electrical devices and for gases and for dusts. The principles allow for a design in various safety categories in accordance with the Directive 94/9/EC or the Equipment Protection Level (EPL) according with EN 60079-0 ff:

Category 1 - with very high level of protection and thus a very high degree of safety

Category 2 - with high level of protection and therefore a high degree of safety

Category 3 - with normal level of protection and therefore a conventional degree of safety

EPL a – with very high level of protection and thus a very high degree of safety

EPL b – with high level of protection and therefore a high degree of safety

EPL c – with normal level of protection and therefore a conventional degree of safety

### Non-technical measures

The requisite preconditions for the safe operation of electrical equipment in potentially explosive atmospheres are created in a joint effort by the manufacturers of explosion protected equipment and the constructors and operators of industrial plants. It is important that the operator of such plants should ensure that their personnel know how the danger of explosions is likely to arise and the measures that are to be taken to prevent it.

The employees should be regularly trained on the contents of the explosion protection document in accordance with the Directive 1999/92/EC (occupational safety regulations) and informed by means of written corporate regulations which should be regularly updated.

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## B3. Certified copy of Compressed Air Cylinder

FLO/TV-MAR Kvalitetssystem

TRYKKPRØVERAPPORT

| | | |
|---|---|---|
| Arbeidsordre nr.: 357011873 | Rapport nr.: | - - - |
| | | År - ID - Arkiv nr. - Løpe nr. |

Beholder nr.: 601327 Beholder produksjons år: 07 2001

Type: Luftflaske på 300.bar 50.L

Bruker: Høyskolen i Narvik.

Trykkprøve dato: 20 06 2012 Neste trykkprøve dato: 06 2017

Innhold: 50,7 LTR

Arbeidstrykk: 300 BAR

Prøvetrykk: 450 BAR

Beholdervekt: 74,4 KG

Prøvemanometer brukt ved test:

Merknader:
Det er utført kontroll og vann trykkprøving av flaske til et prøvetrykk på 450.bar
Det er ingen rust eller teringer i flasken.
Flasken besto de gjeldene krav under trykkprøving og er GODKJENT
Flasken er tideliger brukt som Inergen flaske i et slokkeanlegg på båt.
Flasken er kontrollert og ny flaskeventil er monter , flasken er godkjent til bruk for press luft opp til 300.bar

| | |
|---|---|
| Godkjent | ☒ |
| Ikke godkjent | ☐ |

Ramsund, 20/06 - 2012

Signatur:Lars A Søfting

FLO / TV / MAR - Nord
Dykkerverkstedet
9442 Ramsund

Ansvarlig, FLO/TV/MAR-Nord
9442 Ramsund

Blankett, dok nr: 1062r1 dato: 31.08.2005 godkjent til bruk: Lars A. Søfting Side: 1 av 1

## B4. Certified copy for flexible pipe, Filling and Relief solenoid Valves, Pressure gauges, and Valve Regulator



**Servicerapport** **Forsvarets logistikkorganisasjon/ Tungt vedlikehold/ Maritim**

| | | | |
|---|---|---|---|
| | | Postadresse | 9442 Ramsund |
| **Arbeidsordrenr** | | Telefon | 76918000 |
| 357011873 | | Telefaks | 76918397 |

| | | |
|---|---|---|
| **Avdeling/Fartøy** | 5045Z FLO/TV/MAR-NORD SIVILE OPPDRAG ROS | **Kontaktperson** |
| **Utstyr** | | Knut Ravlo |
| **ULnr** | 999999 IKKE SJØFORSVARETS MATERIELL | **Fagansvarlig** |
| **Strukturelement** | 10003630 MEKANISK VERKSTED | |
| **NIIN** | | **Referanse** |

**Oppdrag**

Ferdigstillelse av Schock Tube på Fjelldal NBSK

**Beskrivelse av oppdrag**

høgskolen i narvik ønsker å engasjere maritim nord ramsund til følgende:

ferdigstillelse av schock tube på fjelldal i.h.t. de avtaler som ble gjort på møtet/survey
ros-analyse av laboratoriet .
sertifikat på ht anlegg utstedes og leveres med.

dersom prosjektet ansees å koste mer en ca 35 000,- vennligst ta kontakt med undertegnede!

knut ravlo, tlf 926 64 610

**Utførelsesverksted** 50725 FLO/TV/MAR-NORD-SKIP-DYKKER

**Ordreansvarlig** Nils Otto Stenbro

**Beskrivelse av utførelsen**

29.6.2012. Det er konstruert og tilvirket 1 stk fordelingspanel med slanger, rør, ventiler, manometer og regulator. Det leveres også 1 stk 50 liter, 300 bars luftflaske. Fordelingspanel med slanger og luftflaske er levert og montert ved NBSK.

| | |
|---|---|
| **Arbeid startet** | 00:00:00 |
| **Arbeid avsluttet** | 00:00:00 |
| **Antall timer** | Ingen registrerte timer |

Skrevet ut av Nils Otto Stenbro 29.06.2012

**Kundens godkjenning**

Arbeidet er utført som beskrevet og er godkjent.

Navn ____________________

Stilling/grad ____________________

Kommentar ____________________

**Representant verksted**

FLO / TV / MAR - Nord
...kstedet

For Lars A Søfting

Signatur

# B5.Testing and Approval of Solenoid Valves

ASCO | Certificates can be downloaded from: www.asconumatics.eu

KEMA

(1) **EC-TYPE EXAMINATION CERTIFICATE**

(2) **Equipment and protective systems intended for use in potentially explosive atmospheres - Directive 94/9/EC**

(3) EC-Type Examination Certificate Number: **KEMA 98ATEX2542 X** Issue Number: **6**

(4) Equipment: **Solenoid Valve Operator Type EM-M...**

(5) Manufacturer: **Asco Controls B.V.**

(6) Address: **Industrielaan 21, 3925 BD Scherpenzeel, The Netherlands**

(7) This equipment and any acceptable variation thereto is specified in the schedule to this certificate and the documents therein referred to.

(8) KEMA Quality B.V., notified body number 0344 in accordance with Article 9 of the Council Directive 94/9/EC of 23 March 1994, certifies that this equipment has been found to comply with the Essential Health and Safety Requirements relating to the design and construction of equipment and protective systems intended for use in potentially explosive atmospheres given in Annex II to the directive.

The examination and test results are recorded in confidential test report number 210962800.

(9) Compliance with the Essential Health and Safety Requirements has been assured by compliance with:

**EN 60079-0 : 2006** **EN 60079-7 : 2007** **EN 60079-18 : 2004**
**EN 61241-0 : 2006** **EN 61241-1 : 2004**

(10) If the sign "X" is placed after the certificate number, it indicates that the equipment is subject to special conditions for safe use specified in the schedule to this certificate.

(11) This EC-Type Examination Certificate relates only to the design, examination and tests of the specified equipment according to the Directive 94/9/EC. Further requirements of the directive apply to the manufacturing process and supply of this equipment. These are not covered by this certificate.

(12) The marking of the equipment shall include the following:

**II 2 G Ex e mb II T3 ... T6**
**II 2 D Ex tD A21 IP6X T85 °C ... T200 °C**

This certificate is issued on July 20, 2009 and, as far as applicable, shall be revised before the date of cessation of presumption of conformity of (one of) the standards mentioned above as communicated in the Official Journal of the European Union.

KEMA Quality B.V.

C.G. van Es
Certification Manager

Page 1/3



KEMA Quality B.V. Utrechtseweg 310, 6812 AR Arnhem P.O. Box 5185, 6802 ED Arnhem The Netherlands
T +31 26 3 56 20 00 F +31 26 3 52 58 00 customer@kema.com www.kema.com Registered Arnhem 09085396

Experience you can trust.

A/N: 131-292-283

CER 040c-R0 / pg. 1 of 2 For IECEx certificates of conformity please visit www.iecex.com

ASCO | Certificates can be downloaded from: www.asconumatics.eu

KEMA

(13) **SCHEDULE**

(14) **to EC-Type Examination Certificate KEMA 98ATEX2542 X** Issue No. **6**

(15) **Description**

Solenoid Valve Operator Type EM-M... to be used for pushing or pulling valve action with mounted valve. Differences in models concern size, rated voltage and power.

Ambient temperature range -40 °C to +90 °C.

The actual ambient temperature range is within these limits and will be marked when it differs from -20 °C to +40 °C.

**Technical data**

The apparatus enclosure provides a degree of protection of at least IP66/IP67 in accordance with EN 60529.

The relation between temperature class, the maximum surface temperature "T" of the enclosure, the ambient and medium temperature and the rated power is shown in the following table:

| Temperature class | Maximum surface temperature "T" (°C) | Ambient/ medium temperature (max., °C) | Nominal power (max., W) Type EM-M6 | Nominal power (max., W) Type EM-MXX | Nominal power (max., W) Type EM-M12 I | Nominal power (max., W) Type EM-M12 II |
|---|---|---|---|---|---|---|
| ac operation only | | | | | | |
| T3 | 200 | 40 | 9,2 | 11,0 | 13,6 | 16,1 |
| | | 65 | 7,0 | 8,4 | 10,4 | 12,3 |
| | | 90 | 4,3 | 4,5 | 6,4 | 6,6 |
| dc or ac (rectified) | | | | | | |
| T3 | 200 | 40 | 12,5 | 13,0 | 16,0 | 20,1 |
| | | 65 | 8,7 | 9,4 | 10,9 | 13,5 |
| | | 90 | 4,4 | 4,6 | 5,3 | 7,0 |
| T4 | 135 | 40 | 7,0 | 7,7 | 9,0 | 11,3 |
| | | 75 | 3,7 | 3,8 | 4,4 | 6,0 |
| | | 90 | 2,3 | 2,6 | 3,0 | 3,9 |
| T5 | 100 | 40 | 3,7 | 3,8 | 4,4 | 6,0 |
| | | 55 | 2,3 | 2,6 | 3,0 | 3,9 |
| | | 75 | 1,0 | 1,1 | 1,3 | 1,6 |
| T6 | 85 | 40 | 2,3 | 2,6 | 3,0 | 3,9 |
| | | 60 | 1,0 | 1,1 | 1,3 | 1,6 |

MEAN-P-Ex30 v2.1.2 Page 2/3

**ASCO CONTROLS BV**
P.O. Box 3, 3925 ZG Scherpenzeel, The Netherlands
Tel. +31(0)33 277 79 11 - Fax +31(0)33 277 45 61 - www.asconumatics.eu

For IECEx certificates of conformity please visit www.iecex.com

## B6. Safety Details for the High Pressure Transducer

| GEMS SENSORS & CONTROLS | |
|---|---|
| OPERATING & INSTALLATION INSTRUCTIONS | |
| **SERIES 3100/3200** | |
| PLEASE READ CAREFULLY BEFORE INSTALLING | |
| **Part Number:** 560550-0111 | **Issue:** A |

**INTRODUCTION**

Series 3100/3200 high output pressure transducers and transmitters are fitted with an Asic providing various optional (at time of order) voltage outputs, and a 4-20mA current output capable of being used in control and indicating loops without further amplification.

Series 3100/3200 with the CE Mark conform to the essential protection requirements of the EMC Directive 89/33/EEC Certified by type testing to EN50082-2 & EN50081-1.

Series 3100/3200 with the CE0086 mark also complies with the requirements of the Pressure Equipment Regulations 1999 and is classed as a safety accessory and can be used as a safety-related device on Category IV pressure equipment. No other product should be used as "Safety Accessories" as defined by the PED Article 1, Paragraph 2.1.3.

**HAZARDOUS PRODUCTS**

The Consumer Protection Act of 1987, Section 6 of the Health and Safety at Work Act 1974 and the Control of Substances Hazardous to Health Regulations 1988 require that we advise recipients and users of our products of any potential hazards associated with their storage, handling or use.

The products which our Company supplies may be classified as Electrical, Electro-Mechanical and Electronic equipment.

These products are tested and supplied in accordance with our published specifications or individual special requirements that are agreed in writing at time of order. They are constructed so as not to affect adversely the safety of persons and property when properly installed, maintained and used by qualified personnel, in the applications for which they were designed and manufactured.

**Conformity with the requirements of the CE mark only applies when the installation conditions described in these instructions have been met. For units supplied without a cable assembly connection to the transducer must be accomplished using Gems Sensors & Controls approved cable. See RECOMMENDED CABLE section.**

**GENERAL**

* Transducer should not be subjected to greater than the maximum allowable pressure (P.S.)
  / Temperature (T.S) as defined on the transducer label.
* Transducer should not be subjected to mechanical impact.

560550-0111 Issue A Page 1 of 5

## B7. The certified copy for Hydrostatic Pressure Test of shock

**FABWELD**

QUALITY FABRICATIONS

Fabweld New Mills Ltd.
Unit 5, Canal Foundry,
Albion Road,
New Mills, High Peak. SK22 3EZ
Telephone: 01663 746156 Fax: 01663 747960
E-mail: fabweldnewmills@tiscali.co.uk

# HYDROSTATIC TEST CERTIFICATE

**Customer Hogskolen I Narvik** **Customer's O/No B-10-10-28**

**Works O/ N J5138** **Date of Order 18.11.10**

**Pipework** [ X ] **Tank** [ ] **Vessel** [ ]

**Description of Equipment Tested**

Stainless Steel Shock Tube.

**Test Equipment** **Hand Pump** **Gauge Certificate Number 74039-5**
**80019-1**

**Test Medium** **Water** **Test Pressure** **150 Bar** **Duration 30 mins**

**We certify that the equipment has been hydrostatically tested in accordance with our Quality Control Procedure and has been found to be satisfactory.**

**Signature:** ........................... **Date:** 21 – 3 – 11

QA5 Rev.0

ZURICH 21/3/14.

## B8. The certified copy of Pressure Equipment Regulation

ZURICH

# *Pressure Equipment Regulations 1999*
## *Certificate of Conformity - EC Unit Verification*
form PER G

CERTIFICATE REFERENCE: CEN-070900/001

| | |
|---|---|
| MANUFACTURER NAME | Fabweld New Mills Ltd. |
| ADDRESS | Unit 5 Canal Foundry<br>Albion Road<br>High Peak<br>SK22 3EZ |
| MANUFACTURER REFERENCE | 9615 / 5138 |

| | |
|---|---|
| EQUIPMENT DESCRIPTION | Shock Tube |
| CONSTRUCTION CODE | PD 5500 Cat 1 2009 |
| SERIAL NUMBER | |
| DRAWING NUMBER(S) | Shock Tube GA Edition 2. |
| DESIGN PARAMETERS | 105 bar g at 30 deg C |
| PRESSURE TEST DETAILS | Tested to 150 bar g for 30 minutes on 21/03/2011. |

*This is to certify that the pressure equipment identified above was subjected to EC Unit Verification, including examination during and upon completion of manufacture, as required by the code of construction and inspection specification, and was found to meet with the provisions of the Pressure Equipment Regulations 1999, subject to any conditions of use specified below.*

*Zurich Engineering*
*Authorised Signatory*

*Title: Senior Engineer*

ZURICH
SAFed / CEOC MEMBER COMPANY
ZURICH ENGINEERING
126 Hagley Road, Edgbaston
Birmingham B16 9PF
Tel: 0121 456 1311

*Notified body No: 0037*

*Date:* 27/04/2011

Zurich Engineering, 126 Hagley Road, Edgbaston, Birmingham B16 9PF. Telephone: 0121 456 1311 Fax: 0121 697 9136 Email: engineering@uk.zurich.com

# Appendix C: Standard Operating Procedure on Shock Tube Setup

## C1. Operation Manual of TML_Coating Material to the Strain Gauge

### OPERATION MANUAL OF TML COATING MATERIAL TYPE N-1

The N-1 is a coating material for TML strain gauges and used for moistureproofing of strain gauges bonded on metal or nonmetal surface. The N-1 is single component chloroprene rubber system coating material and has an excellent moisture proofing. The N-1 is light yellow liquid in tube and gets dry at room temperature to form a moisture-proof layer by merely applying with a brush.

### 1 SURFACE PREPARATION

*The following work should be finished before gauge installation.*

(1) Remove moisture, grease, scale, rust, paint, etc. from the bonding area to present the foundation of a test piece.

(2) Grind an area a bit larger than the bonding area uniformly with abrasive paper. Finish should be achieved with abrasive paper #120 ~ 180 for steel and #240 ~ 320 for aluminium. Consult supplier for other materials.

(3) Clean the abraded area with industrial tissue paper or cloth soaked in a small amount of chemical solvents such as acetone. Cleaning should be made until the tissue or cloth is kept contamination free.

### 2 GENERAL APPLICATION PROCEDURES

(1) Bond the strain gauges in the specific manner and connect lead wires.

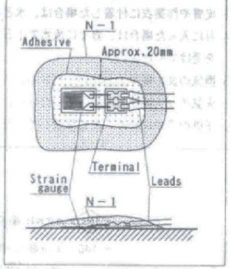
(2) Make sure again that a coating area is thoroughly cleaned.

(3) Apply the N-1 over the strain gauge, terminal and adhesive around the gauge and under the lead wires in a thickness of 1 ~ 2mm with a brush or directly from the tube.
The gauge and metal-exposed terminal part should be coated well.

(4) The hardening time depends on the material of a test piece, temperature, etc. The N-1 hardens and drys in a half day at room temperature. For more precise measurement, it is recommended to leave it for more than 24 hours.

(5) Wherever the coating layer is apt to become comparatively thin, lap-coat to make up moisture-proof layer with uniform thickness.

**Fig.1 Coating area of N-1**




TML manu N1002E

### 3 STORAGE AND HANDLING

(1) After use, wipe coating material out of container and nozzle with cloth, etc. and replace the cap.

(2) After use, put back in package and store in a cool, dark place without flame.

(3) After handling, wash hands well.

(4) If there is any question, consult TML or your nearest TML agent. A material data sheet is available on request.

(Table)

| | |
|---|---|
| Contents | 90g |
| Components | Chloroprene system rubber |
| Operating temperature | −30 ~ +80℃ |
| Shelf life | 6 months in cool dark place such as refrigerator (5-10℃, freezer prohibited) |

**⚠ CAUTION**

1. Avoid contact with skin, eyes and clothing.
2. Skin contact and vapor inhalation may cause a damage. As occasion arises, wear a protect glove or goggle.
3. If coating material adhered to skin or clothing, wipe off with water and soap thoroughly.
4. In case of getting in eyes, flush eyes well with water for more than 15 minutes and call for medical aid.
5. Use in a well-ventilated area.
6. Handle in a place without flame.
7. Store away from children.

Made in Japan

TML Tokyo Sokki Kenkyujo Co., Ltd.
8-2, Minami- Ohi 6- Chome
Shinagawa- Ku, Tokyo 140

**References**

1. Ji, H., Mustafa, M., Khawaja, H., Ewan, B., Moatamedi, M. *Design of water shock tube for testing shell materials*. World Journal of Engineering 2014; Volume 11 (1). ISSN 1708-5284.s 55 - 60.s doi: 10.1260/1708-5284.11.1.55.

2. Khawaja, H., Moatamedi, M. *Multiphysics Investigation of Composite Shell Structures Subjected to Water Shock Wave Impact in Petroleum Industry*. Materials Science Forum 2013. ISSN 0255-5476.s doi: 10.4028/www.scientific.net/MSF.767.60.

3. Khawaja, H., Bertelsen, T., Andreassen, R., Moatamedi, M., *Study of CRFP Shell Structures under Dynamic Loading in Shock Tube Setup*. Journal of Structures 2014; Volum 2014 (2014). ISSN 2356-766X.s doi: 10.1155/2014/487809.

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