वैज्ञानिक तथा औद्योगिक अनुसंधान परिषद्
Council of Scientific & Industrial Research
राष्ट्रीय वांतरिक्ष प्रयोगशालाएं
National Aerospace Laboratories

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ISO 9001 : 2015
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INVITATION FOR BIDS/NIT

Tender No. NAL/PUR/STTD/539/20-Y **Dated: 19-Mar-2021**

CSIR- National Aerospace Laboratories (NAL), Bengaluru, India is one of the premier laboratories under Council of Scientific and Industrial Research (CSIR), an autonomous body under Department of Scientific and Industrial Research, Government of India, New Delhi. CSIR-NAL is a Science and Knowledge based Research, Development and Consulting Organization. It is internationally known for its excellence in Scientific Research in Aerospace Engineering.

The Director, CSIR-NAL invites online quotation for procurement of the following item(s) for day to day research work.

Sl.No.	Description of Items	Unit	Quantity
1	**Movable compression / tensile SHPB Gasgun with Aligned mounting table** **Please refer annexure for detailed specification**	**Set**	**1**

Single / Double Bid	**Two Bid**	Tender Type	**Open**
Bid Security (EMD) (in INR)	Bid Security Declaration should be enclosed with quotation	**Bid submission end date**	**08-Apr-2021 10.00 Hrs**
Performance Security	**3% of the purchase order value**	**Bid opening date**	**09-Apr-2021 11.00 Hrs**

01. Tender Documents may be downloaded from Central Public Procurement Portal https://www.etenders.gov.in. Aspiring Bidders who have not enrolled/ registered in e- procurement should enroll/ register before participating through the website https://www.etenders.gov.in. The portal enrolment is free of cost. Bidders are advised to go through instructions provided at 'Instructions for online Bid Submission'.

02. Tenderers can access tender documents on the website (For searching in the NIC site https://www.etenders.gov.in, kindly go to Tender Search option, select tender type and select ' Council of Scientific and Industrial Research' in organization tab and select NAL-Bengaluru-CSIR in department type Thereafter, Click on "Search" button to view all CSIR-NAL, Bengaluru tenders). Select the appropriate tender and fill them with all relevant information and submit the completed tender document online on the website https://www/etenders.gov.in as per the schedule given in the next page.

03. Either the Indian Agent on behalf of the Foreign principal or the Foreign principal can bid directly in a tender but not both. However, the offer of the Indian Agent should also accompany the authorization letter from their principal. To maintain sanctity of tendering system, one Indian Agent cannot represent two different Foreign principals in one tender.

04. Unsolicited / conditional / unsigned tenders (Quotations)/Quotations received after the due date and time **shall be summarily rejected**. The Bidder shall comply the terms and conditions of the tender, failing which, the offer shall be liable for rejection.

05. The Bidders proposing to supply finished products directly/indirectly from vendors of countries sharing the land border with India should submit copy of registration done with the Ministry of Home Affairs and Ministry of External Affairs.

06. If the Products supplied are not from vendors of countries sharing land border with India, the Bidders have to enclose a declaration to that effect.

The bids of those Bidders failing to comply with the above clauses will be summarily rejected.

19/3/21

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07. Bidders are requested to refer to the instruction regarding Procurement Policies for Make in India issued by Ministry of Commerce and Industry, Department of Industrial Policy and Promotion dated. 28-May-2018 and 4-Jun-2020 and guidelines as and when issued.

08. The prospective bidders are requested to refer to the Standard Terms and Conditions available on NAL Internet (www.nal.res.in) under the icon Tender-Purchase before formulating and submitting their bids

09. The Director, CSIR- National Aerospace Laboratories, Bengaluru reserves the right to accept any or all the tenders either in part or in full or to split the order without assigning any reasons there for.

Raman Kumar
Stores & Purchase Officer

The specifications for Platform and Airgun assembly for the Integrated Tensile-Compressive Split Hopkinson Bar Setup

The platform consists of the following

1) Table
2) Rail/Base/Slide
3) Saddle/Bar Support with dovetail arrangement
4) Momentum Trap
5) Bar Supports
6) Double Chamber Reservoir with Barrel

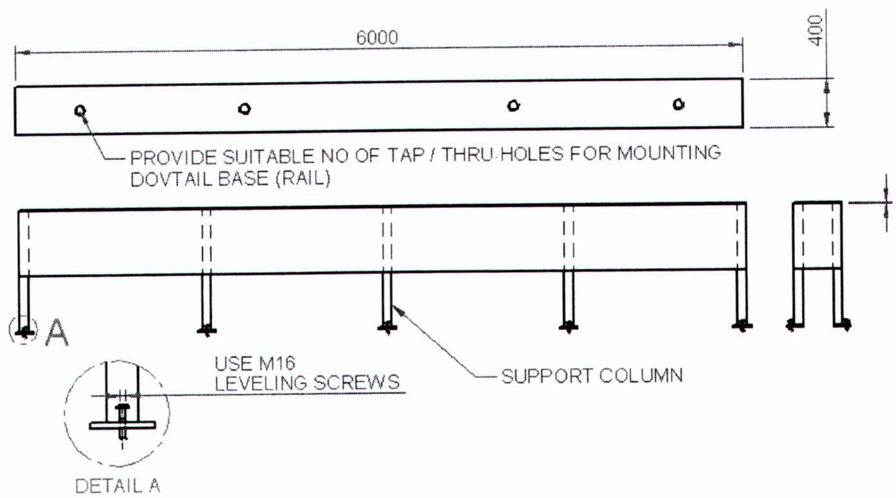
The design of the important components like the table, barrel and reservoir is available in the design report which is attached. The drawings supplied in the spec is simple and self-explanatory. The vendor can check both before quoting.

1. Specification for the Table:

1	Dimension:	6000 mm (Length) X 400 mm (Breadth) X 1000 mm (Height) (Refer Figure 1)	
2	Number	1 Table	
3	Material:	Mild Steel/ Low Carbon Steel	
4	**Chemical Composition**		

Element	Carbon	Chromium	Mn	Phosphorus	Sulfur		Fe
Weight%	0.14-0.2	11%	0.6-0.9%	0.04 max	0.05		Bal

5	Strength (Tensile)	370MPa	
6	Hardness	126 Brinell	
7	Finish	Matt Paint Finish with Glossy Top Plate	
8	Levelling Screws	M16 Levelling Screws should be provided. (Refer Figure 1)	
9	Selection of Fasteners:	Vendor can decide the size and number of fasteners based on the maximum load	
10	Finish and Tolerance/Alignment	Tolerance of 0.1mm/m throughout 6 meters of base	



NOTE : ABOVE DRG IS FOR REFERENCE VENDER MAY VARY THE THE DIMENSONS AND THICKNOESS OF THE MATERIAL WITH IN THE DESIGN LOAD LIMIT.
ALL MATING SURFACES TO BE MAHINED AT ROUGHNESS VALUE OF N7-N9 (1.6-3.2 Ra)
MINIMUM 4 SUPPORT COLUMNS SHOUD BE PROVIDED

MATERIAL : MILD STEEL / LOW CARBON STEEL
QTY : TABLE 1 NO

Figure 1 :Table for the Split Hopkinson Bar

2. Rail Base/Slide:

1	Dimension:	Total length of 6metres, (smaller units can be fitted to achieve this) (Refer Figure 2)	
2	Material:	Mild Steel/ Low Carbon Steel	
3	Numbers	Can be a single monolithic piece or number of pieces attached.	
4	**Chemical Composition**		

Element	Carbon	Chromium	Mn	Phosphorus	Sulfur	Iron		Fe
Weight%	0.14-0.2	11%	0.6-0.9%	0.04 max	0.05	98.81-99.6		Bal

	Alignment	0.1mm/m	
5	Strength (Tensile)	370MPa	
6	Modulus of Elasticity	205 GPa	
7	Hardness	126 Brinell	
8	Finish	Smooth finish with 1mm tolerance	

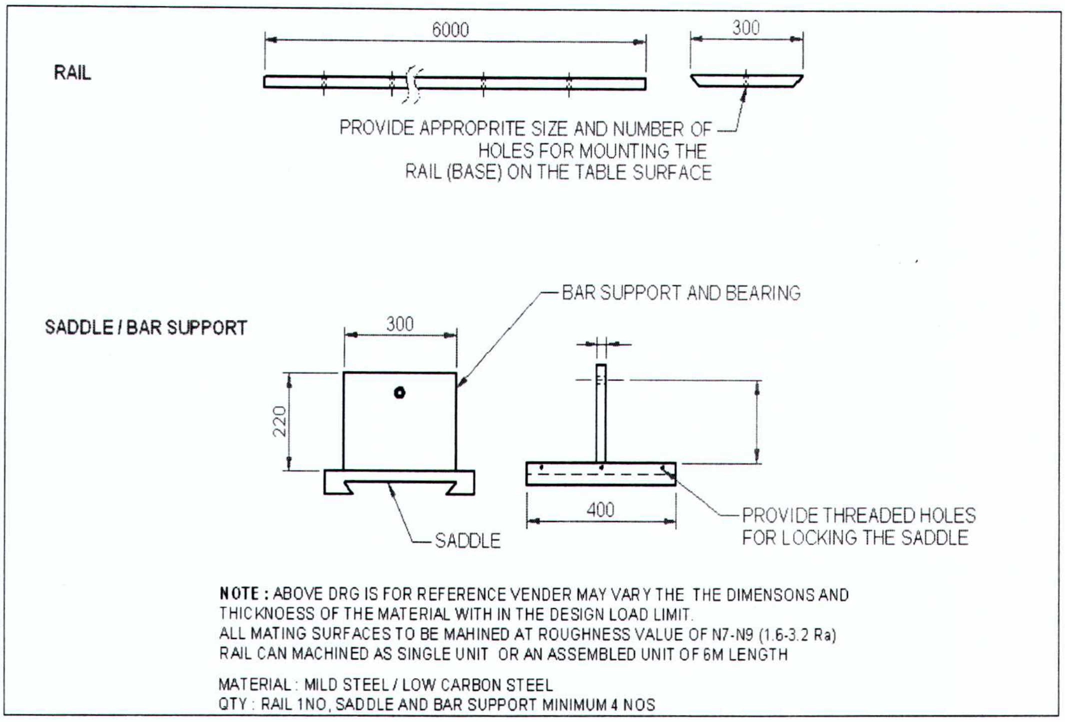


Figure 2: Rail, Bar Support and Dovetail arrangement

3. Dovetail arrangement for the bar holders:

1	Dimension	400 mm (Length) X 300 mm (Breadth) X 220 mm (Height) (Refer Figure 2)	
2	Number of arrangement for each bar	4	
3	Material:	Mild Steel/ Low Carbon Steel	
4	**Chemical Composition**		

Element	Carbon	Chromium	Mn	Phosphorus	Sulfur	Iron			Fe
Weight%	0.14-0.2	11%	0.6-0.9%	0.04 max	0.05	98.81-99.6			Bal

5	Strength (Tensile)	370MPa	
6	Modulus of Elasticity	205 GPa	
7	Hardness	126 Brinell	
8	Finish	Smooth finish with 1mm tolerance	

4. **Bar Supports:**

1	Dimension:	25 mm (Length) X 250 mm (Breadth) X 220 mm (Height) (Refer Figure 2)	
2	Number of bar supports for each bar	4	
3	Material:	Mild Steel/ Low Carbon Steel	
4	**Chemical Composition**		

Element	Carbon	Chromium	Mn	Phosphorus	Sulfur	Iron			Fe
Weight%	0.14-0.2	11%	0.6-0.9%	0.04 max	0.05	98.81-99.6			Bal

5	Strength (Tensile)	370MPa	
6	Modulus of Elasticity	205 GPa	
7	**Hardness**	**126 Brinell**	
8	Type of sleeves in the bar supports	Brass Bush with End Lockers	
9	**Finish**	Smooth finish with 0.1mm tolerance	

5. **Momentum Trap:**

1	Dimension:	400 mm (Length) X 200 mm (Breadth) X 30 mm (Height) (Refer Figure 3)	
2	Number	1 Momentum trap	
2	Material:	Mild Steel/ Low Carbon Steel	
3	**Chemical Composition**		

Element	Carbon	Chromium	Mn	Phosphorus	Sulfur	Iron			Fe
Weight%	0.14-0.2	11%	0.6-0.9%	0.04 max	0.05	98.81-99.6			Bal

4	Strength (Tensile)	370MPa	
5	Modulus of Elasticity	205 GPa	
5	**Hardness**	**126 Brinell**	
6	**Finish**	Smooth finish with 1mm tolerance	

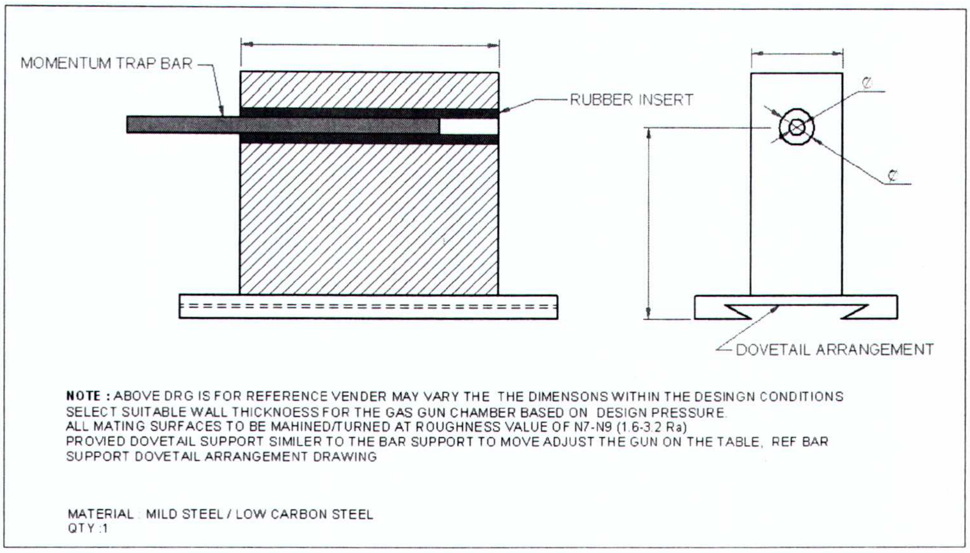


Figure 3: Momentum Trap

6. Double Chamber Reservoir with barrel:

1	Type of reservoir and barrel	Double chamber as shown in Fig 6	
2	Dimension of the chamber (second reservoir)		
	Outside diameter of outside reservoir (first chamber) and second chamber (refer fig 6) (Note: The outside chamber is connected pneumatically to the pressure source from outside.)	100mm	
	Length of outside reservoir (first chamber in fig 6)	250mm	
	Length of second reservoir (second chamber in fig 6)	500mm	
	Total Length of barrel (refer fig6)	1200mm	
	Internal Diameter of barrel	32mm	
3	Numbers	1 double chamber reservoir with barrel	
4	Material:	Stainless Steel	
5	**Chemical Composition**		

Element	Carbon	Chromium	Molybdenum	Phosphorus	Sulfur	Iron			Fe
Weight%	0.14-0.2	12%	1%	0.04 max	0.05	98.81-99.6			Bal

6	Strength (Tensile)	250MPa	
7	Minimum combined Volume of the first and second chamber	7 Litres	
8	Solenoid valves	2 (one of the valves for opening into the second chamber from the first chamber and other for	

		the opening into the barrel from the second chamber.) Pressure rating :40 bars (The vendors should also make sure that there is no interference of the solenoids on data collected.)	
9	Pressure Rating for the reservoirs	100 Bars	
10	Finish	Smooth finish with 1mm tolerance	
11	Vents for safe release of pressurized gas. These Vents should be provided at the end of the barrel length. This would prevent any change in velocity of the striker after it has crossed the vents and would be constant when it hits the incident bar.		
12	The suppliers should supply the pressure vs velocity curve for a 250 mm striker (can check in Design Report) within an accuracy of 5% through their own testing		
13	The end of the barrel should accommodate the incident bar when it is used for the tensile setup. It should be completely closed and sealed when used for the compressive split Hopkinson bar. For this, the components of the airgun and barrel should be removable and adjusted for both the setups. The vendors can find the details of this requirement in the Design report for the Integrated compressive tensile setup.		
14	Inlets should be provided at the chambers for letting the gas in at required pressures from outside source.		

Abstract

Determination of high and intermediate strain rate properties is a must if you have to design structures subjected to high and low velocity impact. There are many circumstances when aircraft structures are subjected to high and low velocity impact which requires High Strain Rate Models in simulation. Therefore, the Impact and Crashworthiness group, Structures NAL have decided to acquire a Split Hopkinson Bar facility in tension and compression. In this regard a design report highlighting the design of the important features of an Integrated Compression Tension Split Hopkinson bar is presented. The various components for the bar will later be acquired/manufactured from experienced vendors.

1. Introduction

There are circumstances under which an aircraft or aircraft component may be subjected to high or low velocity impact. For example, a Bird hit on a wing or a windshield is a high velocity impact event. Other high velocity impact events on aircraft include Foreign Object Damage (FOD) or Debris impact. An emergency landing on a water body or ditching is a low velocity impact event. In all these events described above the components of the aircraft are subjected to inelastic loading and undergo high strains and strain rates. It is well known that metals, composites and polymers behave differently at high strain rates of loading. They generally tend to harden with higher strain rates and the failure behaviour also differs at higher strain rate. Therefore it is imperative to test and model the behaviour of these materials at high strain rates. These high strain rate material models should be used to predict the behaviour of aircraft structure during the high/low velocity event. Generally, the failure of any material is studied during tension loading rather than compression loading as most materials like metals fail in tension. Composites on the other hand fail in compression and shear. Therefore, it is necessary to study the failure and stress-strain behaviour in both tension and compression.

The Split Hopkinson Bar is a device used worldwide to determine the high strain rate properties of material in both compression and tension. Therefore, the Impact and Crashworthiness Group of Structures Division, NAL has decided to acquire a tension and compression Split Hopkinson Bar which would satisfy the objective of high strain rate testing and modelling. In this context, a design report is prepared for an integrated tensile-compressive Split Hopkinson Bar. The components of the bar designed will be acquired or manufactured and will be assembled at site. Experienced vendors who have worked on similar projects have been identified and the components so designed will be acquired / manufactured from them.

2. Split Hopkinson Bar Principle

The Split Hopkinson Bar has been used since the 1960's to measure the high strain rate properties of different materials. The Split Hopkinson Bar utilizes the principle of one dimensional wave propagation in rods made of metals. Through this one dimensional, wave, a very high rate of force or deformation can be applied on to a sample in a very short duration. Since the wave speed in metals is high, a very high strain rate can be generated on a sample which is placed between two metal rods of same material. Generally, there are three type of Split Hopkinson Bar, namely Compressive, Tensile and Torsion. Any split Hopkinson bar consists of an incident bar and a transmitted bar. The sample or specimen whose strain rate properties are to be determined is placed between the incident and transmitted bar. A striker bar, propelled usually by compressed air is made to impact the incident bar. A stress wave is generated in the incident bar (ε_i) due to this impact This wave travels along the length of incident bar and interacts with the sample. A part of this wave is reflected (ε_r) and a part is transmitted (ε_t) into the transmitted bar. From the reflected wave (using strain gauge), the strain in the material or specimen is determined as in equation (1). From the transmitted wave, the stress is calculated as in equation (2). These equations are derived on the assumption that there is one dimensional wave propagation in the bar and the incident and transmitted bars do not cross the yield stress. By varying the velocity of striker and sample thickness, stress-strain curves at different strain-rates can be obtained. Figure 1 shows the schematic of the compression testing Split Hopkinson bar.

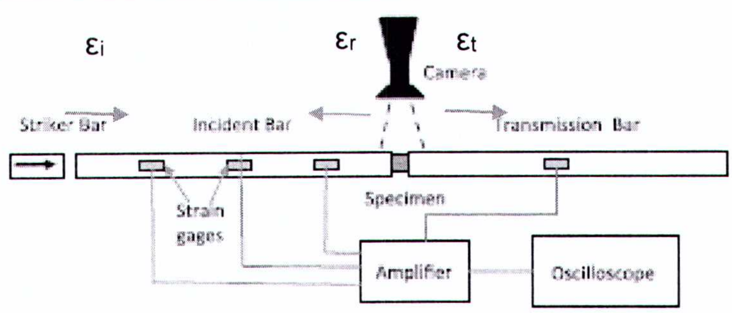


Figure 1: Schematic of the Compression Split Hopkinson Bar [1]

$$\sigma_t = E\left(\frac{A_0}{A}\right)(\varepsilon_t) \qquad (1)$$

$$\varepsilon_s(t) = -\frac{2C_0}{L}\int_0^t \varepsilon_r(t)\,dt \qquad (2)$$

As part of the 12th FYP NAL has developed a compression testing SPHB with strain rate limit of 7000/s with Aluminium material. But, it has to be upgraded for better performance and for higher strain rate by changing some of its existing components like the bars, strikers and the pneumatic components. Its base mounting fixture also has to be improved due to the requirement of higher alignment tolerance and rigidity. Figure 2 shows the photograph of the existing compression SPHB test facility at NAL. Aircraft materials are subjected to high and low velocity impact events like bird hit, debris hit, other FOD's and also during crash.

Therefore, it is important to analyse the high strain rate properties of these materials in both tension and compression.

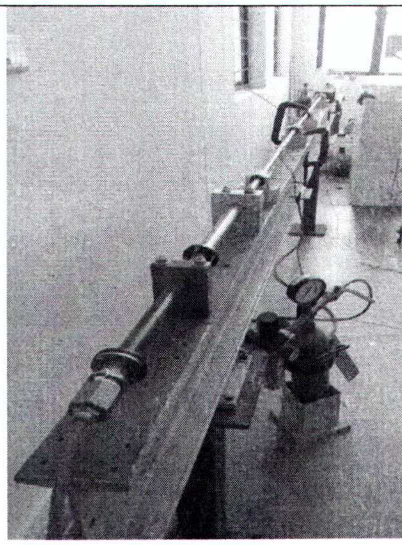


Figure 2: Compression Split Hopkinson Bar at ICSG, STTD, NAL

Under this research project it is planned to upgrade the compression SHPB and also to design and develop a tensile SPHB for dynamic characterisation. Hence it is planned to develop the above setup in same platform which will result in saving of space and cost. Since the tensile and compressive setup is to be achieved in the same platform, it is important to understand the basic Tensile SHPB setup and how it is different from a Compression SHPB setup.

Figure 3 shows the schematic of a tensile Split Hopkinson Bar. As can be seen in the figure, it is more complicated than the compression split Hopkinson Bar as the striker and the pneumatic component (barrel) is integrated with the incident bar. The sample preparation for the tensile test is also more involved when compared to the compressive bar as in the compression test, a cylindrical sample can be simply placed between the two bars. But, it can be understood from looking at the tensile and compressive setups that if one can manufacture the barrel or gun with or without the reservoir, such that it can be shifted and modified to suit for the compression and tensile SHPB setups, one can achieve the objective of an integrated setup.

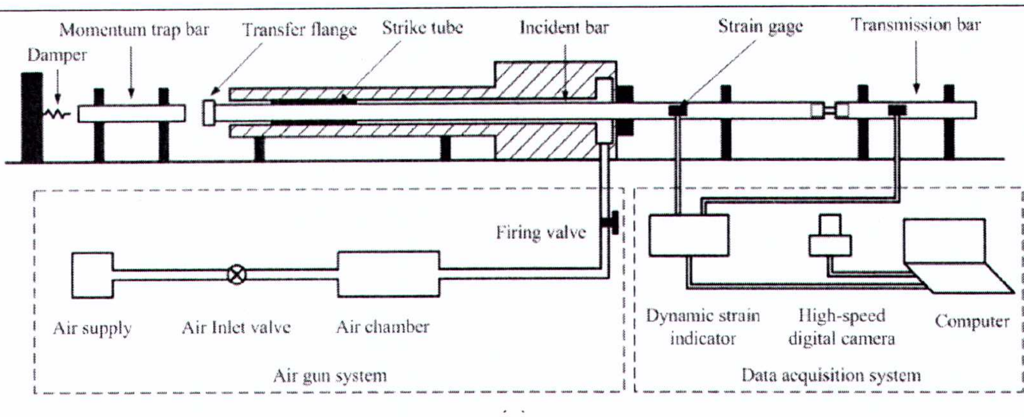


Figure 3: Schematic of the Tensile Split Hopkinson Bar [2]

The scope of this design report is to develop an integrated SHPB with both aluminium and steel bar (to accommodate varied impedances) in a same test platform which will save space and cost and will perform its function of testing high strain rate properties of materials in tension and compression including the strain rate dependence of failure at high strain rates. Some experienced vendors have been identified for this integrated SHPB who have delivered for reputed institutions. The basic design of the SHPB setup such as the dimensions of the bars, the design of the barrel, the design of the momentum traps (especially the compression momentum trap which is not there in many labs) is discussed here. Also, the requirements for the integrated setup which will be put before the vendors is discussed here. This setup will aid in the development of reliable material models which can be used in analysis for proper evaluation of failure. The proper evaluation of failure and behaviour will aid in the design of reliable impact and crashworthy structures. The materials which are sought to be tested in this integrated bar includes a wide variety ranging from metals, Polymers to Composites. The general procedure for operating any Split Hopkinson bar is shown in flow chart in Figure 4.

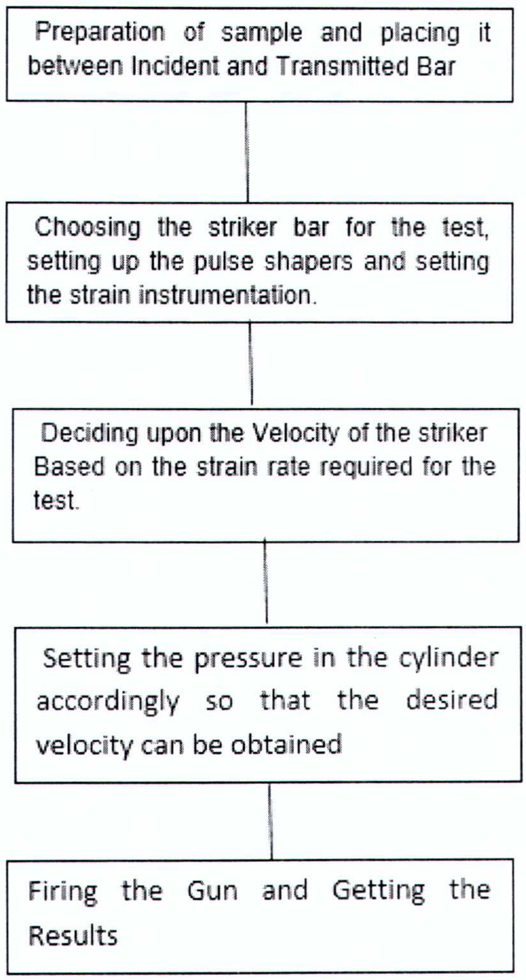


Figure 4: Flowchart for testing of any Split Hopkinson Bar

As, can be seen in Figure 4 that the pneumatic components like the gun/barrel are major components for any SHPB which decide the velocity and hence the strain rate in the sample. The particle velocity, in turn, also determines the stresses in the bar and the sample. Therefore, the barrel will be discussed in detail along with the other stress wave generating components like the bars, strikers, momentum traps etc. in the next section. Smaller components like pneumatic pipes, connectors etc. are not discussed as standard types will be procured which can withstand the required pressure. The main design philosophy behind this work is to achieve very high strain rates in both the tensile and compressive integrated setup. While attaining the objective of the high strain rates, each component should be safe in terms of stress and must have a good life term or age.

3. Integrated Tensile-Compressive Split Hopkinson Bar Design

In this section, the design of the stress generating components of the Integrated compression-tensile Split Hopkinson Bar is presented. Along with the design, the main requirements are also written which will be put before the manufacturers. Many of the stress determination components which are electronic components are either available and the required will be procured and hence are not presented here. The compressive SHPB is designed for a maximum strain rate of 28000/s and the tensile SHPB is designed for a maximum strain rate of 11000/s.

The main stress generating components of the integrated tensile compressive bar is

1) Bars (Incident, Transmitted and Strikers for both the compression and tensile Split Hopkinson (SPH) bars),
2) Momentum traps for both the tensile and compression SPH bars in the incident and transmitted bar area,
3) Common Aligned Base of both the tensile and compressive SPH Bar for holding the bars and pneumatic components,
4) Common adjustable Barrel for both the compression and tensile SPH bars for propelling the strikers,
5) Common Reservoir or air chamber
6) Bearings for holding and smooth sliding of the bars
7) Specimen Holders/Serrated ends which should be in the incident/transmitted bars for tensile SHPB

3.1 Design of Barrel/Gas Gun for tension and compression Split Hopkinson Bar

The design of the barrel should be such that the barrel/gas gun should be common for both the tensile and compressive Split Hopkinson Bar. The whole system should be such that by the mere rearrangement of the individual components (like barrel, pressure system and momentum traps) and adding some extra components (the incident and transmitted bars), the tensile SHPB can be converted into a Compressive SHPB and vice versa. It is decided that the common barrel has an internal diameter of 32mm and the material used for the manufacture of the bar is EN8 steel with yield strength of 280Mpa. It will be shown by calculation in 3.1.1 that this choice of yield and type of steel ensures safety under the maximum pressure. Usually, the internal diameter of the barrel is kept the same as the diameter of the striker. Such a large Internal diameter is provided here, so that any diameter of the incident bar can be accommodated in the future for the same setup. Accommodation of any diameter bar less than 32mm will be made possible through sleeves. Figure 5 shows the sleeve arrangement for the barrel of the integrated tensile compressive bar with a 16mm diameter striker. The pressure system which can be integrated with the barrel should be such that the maximum pressure generated in the barrel is around 50 bar. Later calculations shown in section 3.3.1 and 3.3.2 prove that the choice of 50 bar is enough to achieve the maximum velocity possible in a Maraging c250 bar.

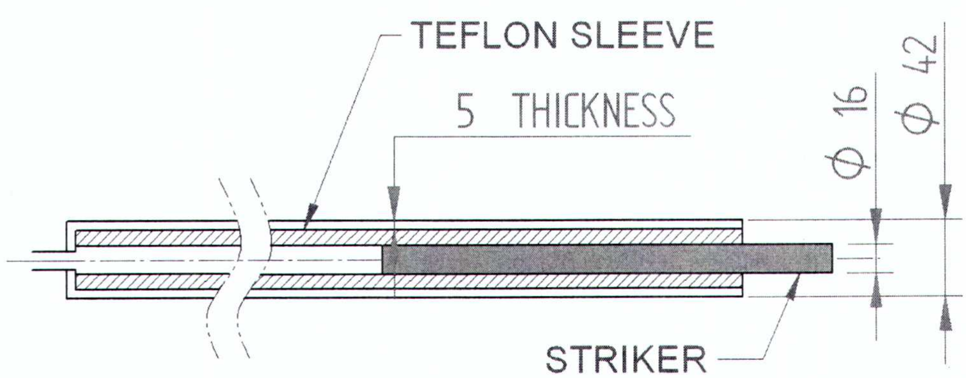


Figure 5 Teflon Sleeve for accommodation of a 16mm diameter striker inside the barrel.

3.1.1 Check for Safety for maximum Pressure in the barrel.

Table below shows the stresses in the barrel and the design validation of the dimensions chosen through the ASME formula and the Strength of Materials approach.

1	The dimensions of the barrel are	32mm internal diameter with thickness t= 5 mm
2	Material of the barrel as EN8 steel with	Yield Stress S=280Mpa yield.
3	The maximum pressure	P = 50 Bar=5x10^6 N/m^2
4	Maximum Hoop Stress assuming small thickness [3]	$= \frac{PD}{2t}$ (3)
5	D= average diameter	=0.5(ID+OD) = 37mm
6	Hence Max Hoop stress from (1)	= 18.5 MPa< 280 MPa Hence the barrel is safe.
7	Also the minimum thickness by ASME formula [4] is given as	$t_c = \frac{PR}{SE-0.6P}$, (4) which comes to 0.362mm taking joint efficiency E as 1. And allowable stress S=280 MPa. Therefore, a thickness of 5mm is highly safe.

3.1.2 Other requirements for the Barrel

The dimensions arevfinalized above based on the condition of the hoop stress being lesser than the yield stress for the barrel. Apart from safety, we require the following requirements for the barrel from the manufacturer.

a) Digital Pressure Monitoring System for monitoring the pressure in the system

b) Vents for safe release of pressurized gas. These Vents should be provided at the end of the barrel length. This would prevent any change in velocity of the striker after it has crossed the vents and would be constant when it hits the incident bar.

c) Solenoid valve for pressure control/switching. This will also aid in quick release of the pressure from the reservoir to the barrel and result in larger velocity of the bar. This would eliminate the arbitrariness of manually releasing the pressure and greater control of the velocity is obtained. But it should be made sure that there should not be interference of the solenoid switching on the strain values and if unavoidable it should be such that it can be filtered out.

d) The end of the barrel should accommodate the incident bar when it is used for the tensile setup. It should be completely closed and sealed when used for the compressive split Hopkinson bar.

e) The manufacturer should give the pressure vs velocity curve for the supplied barrel/reservoir unit through their own experimentation.

3.2 Design of Reservoir

The reservoir stores the pressurized gas from the compressor, in this case air, and sends it to the barrel through the valve. It should meet ASME standards as discussed in 3.1.1 for the barrel. The manufacturer need not supply the compressor as two ELGI compressors with the required pressure exists. The main requirement for the reservoir from the manufacturer is that its volume should be at least four times higher than the volume for the 16mm diameter, 1.2-metre-long passage of air in the barrel. Also, the other requirement for the reservoir is that it should also be well aligned with the barrel and bar, if it is separate from the barrel. The reservoir can be either integrated/assembled with the barrel or separate but preferably integrated so that there is quick release of the air from the reservoir to the barrel. The table below shows the calculation for checks for safety of the reservoir for the dimensions chosen and the calculation of the volume of the reservoir.

1	The volume of the barrel with 16mm dia and 1.2 m passage	3.14*0.008^2*1.2=0.00024m^3
2	Material for the reservoir (Mild steel)	Yield Stress S=200Mpa yield.
3	Internal Diameter of the reservoir assumed	100mm
4	Thickness of the reservoir assumed	16mm
5	Outer diameter of the reservoir	100+2x16=132mm
3	The maximum pressure	P = 50 Bar=5x10^6 N/m^2
4	Maximum Hoop Stress assuming small thickness [3]	$=\frac{PD}{2t}$ (3)
5	D= average diameter	=0.5(ID+OD) = 116mm
6	Hence Max Hoop stress from (1)	= 18.1 MPa< 200 MPa Hence the barrel is safe.
7	Also the minimum thickness by ASME formula [4] is given as	$t_c = \frac{PR}{SE-0.6P}$, (4) which comes to 1.2 mm taking joint efficiency E as 1. And allowable stress S=200 MPa. Therefore, a thickness of 16mm is highly safe.
8	Volume of the reservoir = 15xVolume of the barrel	=15x0.00024=0.0036
9	Length of the reservoir=	0.0036/(3.14*0.05^2) =0.45 The minimum length of the reservoir is

		450mm.

3.3 Design of Strikers for the Integrated Compressive and Tensile Split Hopkinson Bar

The striker for the compressive bar should be solid as shown in figure 5 and that for the tensile bar should be hollow as shown in figure 6. The compression bar striker should be prepared such that it should have slip fit with the barrel or sleeve in the barrel. For the tensile bar the tensile striker should have the same cross sectional area as that of the incident bar. Therefore, if the incident bar diameter is 16mm, the outer diameter of the tensile striker should be 1.414x16=23mm. Therefore the thickness of the hollow striker should be 0.5*(23-16) = 3.5mm. Figure 6 shows the hollow striker within the barrel in the tensile split Hopkinson bar. The striker should be manufactured such that it has slip fit over the incident bar and the barrel or sleeve. The striker material for both the compression and tensile bars should be made of Maraging steel c250 material. The three desired lengths for the strikers for both the compression and tensile bars are 200mm, 300mm, and 400mm. The decision for the final lengths will be made on the cost and budget.

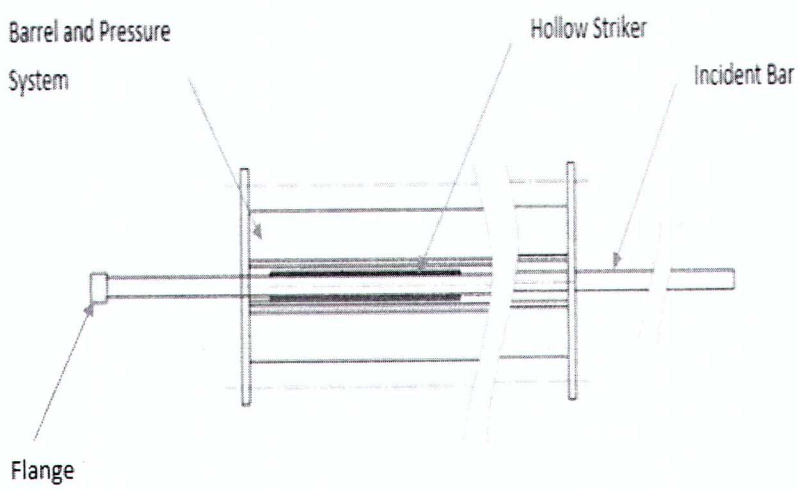


Figure 6:Hollow Striker and the Pressure system within the incident bar in Tensile Split Hopkinson Bar

3.3.1 Maximum Velocity Possible for the striker of the Tension Bar for a 200mm striker

The maximum velocity is possible in only with the striker for the lowest mass which is the 200 mm striker. The table below shows the calculation of the maximum possible velocity for the 200 mm striker.

	The maximum velocity of the striker is calculated by equating the work done by the gas on the striker to the kinetic energy of the striker [7]	$PA_s l_b = \frac{1}{2} m_s V_s^2$ where $V_S = \sqrt{\frac{2PA_s l_b}{m_s}}$
	The maximum pressure	P=5 MPa
	Area of the striker	As=3.14*(0.0115^2-0.008^2)=$2x10^{-4}$ m^2.
	travel distance	Lb= length of barrel=1.20m
	mass of striker (Maraging Steel) mass of striker (Aluminium 7075-T6)	Ms=7890* As*0.20= 0.321Kg Mal=2810* As*0.20=0.1124 Kg
	Therefore, from equation (2) we get the maximum velocity of striker from equation 3 as	Vs (Maraging Steel)=85.5 m/s Vs(Aluminium 7075-T6)=146 m/s

3.3.2 Maximum stress in the strikers for the tensile and compressive SPHB

Since, the maximum stress in the striker would occur only for the highest velocity of impact of the striker, the stress is evaluated below in the table for the highest velocity of 85m/s. This calculation shown in table below is based on the fact that a fair estimation of the maximum particle velocity in the incident bar can be made as half of the total velocity of the striker if the impedance of the striker is same as that of the incident bar [8]. The stress in the incident bar can be calculated based on the particle velocity as

$$\sigma = \rho C V \quad (8)$$

$$\varepsilon = \frac{\sigma}{E} \quad \text{where } E = \rho C^2 \quad (9)$$

Where ρ is the density of the incident bar, C is the wave velocity in the incident bar V is the particle velocity and E is the modulus of elasticity. And since at the interface of the striker and incident bar, stresses are generally same, as the impedance is same, the same maximum value of stress in the incident bar is used for the striker.

1	Maraging c250 steel is used for the incident and transmitted strikers whose yield stress σy	=1650MPa
2	The Young's Modulus for c250 Maraging steel E	=1.9e5 MPa
3	The Wave Velocity in Maraging Steel C	=4873 m/s
4	The maximum velocity of striker Vmax	=85m/s
5	Therefore, the maximum stress in the striker Incident Bar	= ((0.5xVmax)/C)*E =1657MPa

which is almost equal but slightly greater than 1650Mpa,

Therefore, the maximum velocity of striker should be limited to Vmax= (2x1650/1.9x10^5) *4873 =84m/s.

1	Aluminium 7075-t6 is used for the incident and transmitted strikers whose yield stress σy	=503 MPa
2	The Young's Modulus for Aluminium 7075 T6	=7.17e4 MPa
3	The Wave Velocity in Aluminium	=5051m/s
4	The maximum velocity of striker Vmax	=146 m/s
5	Therefore, the maximum stress in the striker Incident	=

	Bar	(0.5xVmax)/C)*E =1036 MPa

which is greater than 503Mpa,

Therefore, the maximum velocity of striker for aluminium should be limited to Vmax= (2x503/7.17x10^4) *5051 =70m/s.

3.3.3 Maximum Velocity Possible for the striker of the Compression Bar for a 200mm striker

The maximum velocity is possible in only with the striker for the lowest mass which is the 200 mm striker. The table below shows the calculation of the maximum possible velocity for the 200 mm striker.

	The maximum velocity of the striker is calculated by equating the work done by the gas on the striker to the kinetic energy of the striker [7]	$PA_s l_b = \frac{1}{2} m_s V_s^2$ (6) where $\boldsymbol{V_S} = \sqrt{\frac{\boldsymbol{2PA_s l_b}}{\boldsymbol{m_s}}}$ (7)
	The maximum pressure	P=5 MPa
	Area of the striker	As=3.14*0.008^2=2x10^{-4} m^2.
	travel distance	Lb= length of barrel=1.20m
	mass of striker (Maraging Steel) mass of striker (Aluminium 7075-T6)	Ms=7890* As*0.20= 0.321Kg Mal=2810* As*0.20=0.1124 Kg
	Therefore, from equation (2) we get the maximum velocity of striker from equation 3 as	Vs (Maraging Steel)=85.5 m/s Vs(Aluminium 7075-T6)=146 m/s

3.4 Design of the Incident, Transmitted Bars for the Integrated Compressive and Tensile Split Hopkinson Bar

The most crucial factor for the correct evaluation of stress and strain in the specimen is one- dimensional wave propagation in the bars. To ensure one-dimensional wave propagation in the bars, ideally, the length to diameter ratio should be infinity. But, it is generally recommended that the L/D ratio should be greater than 60. To avoid bending instablity of the bars in between the supports, literature [7] recommends that their aspect ratio (L/D ratio) should be limited to 100. However, with three-point contact having low coefficient of friction (by using brass sleeves), one can increase the L/D ratio [7]. The length L of the bars is maintained to be 1600 mm while their diameter is fixed by striker bar to be 16mm. We have considered a 16 mm dia rod with 1600 mm length in compression & 2000 mm length in Tension. Both will have an L/D ratio greater than or equal to 100 which is sufficient to capture good strain data. Also, a higher length of incident bar is required for tension SHPB as the gun has to be accommodated in the incident bar. To avoid bending or buckling, supports will be provided which is discussed in other section. The choice of 16mm diameter is based on the idea that a smaller diameter bar shows less dispersion. The present bar which is around 19mm diameter shows a slight dispersion, which is not desirable. Based on the dimensions finalized above, we will have to go for a 5.5-meter base. However, we have considered a base length of 6 meters where in the future one can accommodate larger length bars.

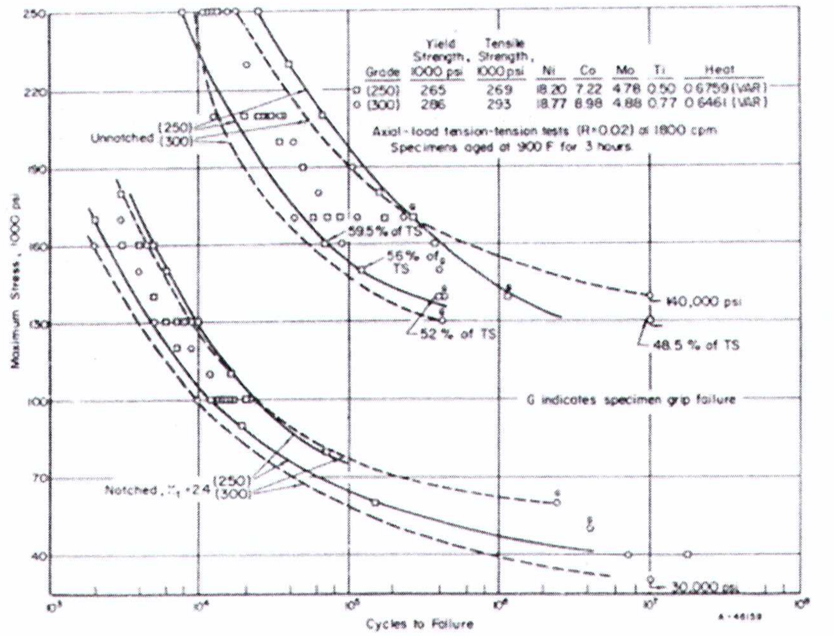
3.4.1 Calculation of number of cycles for failure of the flange in the incident bar for the tensile SHPB

The flange in the tensile SHPB is shown in figure 6. All the flanges should be made of the same material as of the incident and transmitted bar which is maraging steel c250. They should be threaded with sufficient length into the incident bar through ASME M12 thread of 1.75mm pitch. The outer diameter of the flange (minimum) should be 23mm with minimum thread length of 30 mm. Ideally, a one block incident bar with the flange is preferred instead of a threaded one. But, because of budget considerations (for machining and procuring a higher diameter bar), a threaded one is chosen. Also, it is found that choosing the impedance of the striker as same as that of the bar (as chosen in this design) will result in no spurious waves [5]. Many labs all over the world have also chosen a threaded one for these reasons. Here, the design consideration is therefore for providing maximum number of hits or increase the fatigue life for the threaded section so that lifetime of the setup is high. The design of threaded section is done using method from reference [4] in the table below.

1	The yield stress of Maraging steel c250 The yield stress of Aluminium 7075-t6	=1650 MPa =503 MPa
2	The area of contact (A)	$=3.14*(0.023^2-0.016^2)/4=2x10^{-4}$ m^2
3	Therefore, the total force possible $F_{thr\ for}$ maraging Steel Therefore, the total force possible $F_{thr\ for}$ Aluminium 7075-T6	= Yield Stress x A $=1650x10^6x2x10^{-4}$=330kN =Yield Stress x A=503 $x10^6x2x10^{-4}$=100.6 kN
4	Pitch Distance, P	=0.00175m is
5	Height, H	= 0.001515m
6	Minor Diameter, D_{min}	= 0.01072m
7	Major Diameter D_{maj}	=0.01196m
8	Effective half of the resisting distance X	$= (((D_{maj} + H/4) - D_{min})/2)/tan$ 60°=0.00048m (5)
9	Total length of Thread =L	=0.03m
10	Number of threads N	= 0.030/0.00175 = 17
11	Minor diameter for ASME M12 1.75 D_{min}	=0.01072m
12	Circumference length of the minor diameter Ct	$=3.14*D_{min}=3.14*0.01072=0.0336m$
13	Area of thread taking load	=

	A_{thr}	$N(2X)C_t$=17*0.00096*0.0336=0.00056 m^2
14	Shear stress in the thread Sig_{thr}=	F_{thr}/A_{thr}= 600 MPa (for Maraging Steel) F_{thr}/A_{thr}= 180 MPa (for Aluminium 7075-T6)
15	The equivalent normal stress	=$3^{0.5}$*Sig_{thr} (For Maraging Steel)= 1039Mpa which is nearly 60% of yield stress of Maraging steel c250. This will take more than 10^5 cycles to failure with this maximum stress from reference [6] shown in figure 7 for unnotched specimens for Tension tests R=0.02. where R=minimum stress/maximum stress. For R=-1, which is more severe, it will take nearly 60,000 cycles to failure. =$3^{0.5}$*Sig_{thr} (For Aluminium 7075-T6)= 310Mpa which is nearly 60% of yield stress of Aluminium 7075-T6. This will take more than 10^4 cycles to failure with this maximum stress from reference [8] for unnotched specimens for Tension tests R=-1. where R=minimum stress/maximum stress.

Since the velocity of striker will be kept much lesser than that for yield stress (which is around 84m/s as in 2d) the cycles will be much more.



ɩE 25. FATIGUE CURVES FOR 18Ni (250) AND 18Ni (300) MARAGING STEEL BAR 3/4-INCH DIAMETER FROM AXIAL-LOAD FATIGUE TESTS(23)

Figure 7: Fatigue Life curve from Reference [6] for Maraging 250 steel for notched and unnotched specimen and for R=0.02 and R= -1

3.4.2 Maximum stress in the incident and Transmitted bars for the compression SPH bar

Since, the maximum stress in the incident bar would occur only for the highest velocity of impact of the striker, the stress is evaluated below in the table for the highest velocity of 85m/s

1	Maraging c250 steel is used for the incident and transmitted bars whose yield stress σy	=1650MPa
2	The Young's Modulus for c250 Maraging steel E	=1.9e5 MPa
3	The Wave Velocity in Maraging Steel C	=4873 m/s
4	The maximum velocity of striker Vmax	=85m/s
5	Therefore, the maximum stress in the striker Incident Bar	= ((0.5xVmax)/C)*E =1657MPa

Therefore, the maximum stress in the Incident Bar is 1657Mpa which is greater than 1650 MPa

Therefore, the maximum velocity of striker should be limited to Vmax= (2x1650/1.9e5) *4873 =84m/s. Therefore, the safe operating pressure from equation (2) is 45 bar.

3.4.3 Maximum stress in the incident and Transmitted bars for the Tensile SPH bar

Same as discussed in 3.4.2.

3.4.4 Design of Momentum Trap in the Incident Bar for Compressive SHPB

The momentum trap in the incident bar for the compression SHPB is very essential if one wants to evaluate material damage in the material for the first impact. It is important that the reflected wave doesn't come back and inflict further damage in the specimen especially if one wants to evaluate damage for a known velocity of impact or energy of impact. In this regard, the momentum trap does a function similar to the rebound catcher used in Low Velocity Impact Drop tests. The momentum trap in the incident bar is designed as per Nemat-Nasser's design [10] which prevents the reflected wave from causing further damage/compression to the specimen and instead a tensile wave is sent back which causes retraction and allows for material damage evaluation. It consists of the following other three components apart from the incident bar and a flanged or unflanged striker.

1) Hollow Tube
2) Reaction Mass
3) Flange at the start of the incident bar

Figure 8 shows the diagram of the momentum trap. The reaction mass is just a 2-4 kg mass made of any steel block which is placed to arrest the motion of the hollow tube and should have a much larger diameter. The hollow tube should have the same impedance as the incident bar and therefore should be made of Maraging Steel c250 and should have the outer diameter equal to 1.414xInternal diameter=1.414x16= 23mm. The length of the hollow tube is same as that of the striker. The hollow tube made of maraging steel should be manufactured such that it should have slip fit over the incident bar in the compression SHPB. The flange in the compression SHPB should be threaded into the incident bar for sufficient length through ASME thread. The reaction mass should have 1-5 Kg mass and should have slip fit over the incident bar of the compressive SHPB.

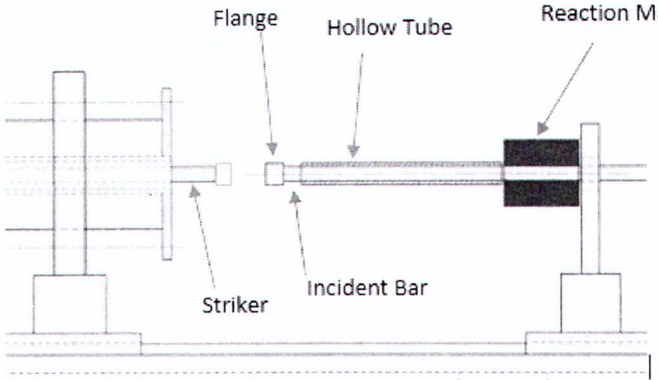


Figure 8 Momentum Trap in the incident bar for Compressive SHPB

3.4.5 Calculation of the cycles to failure for the flange

Same as explained in section 3.4.1

3.4.6 Design of Momentum Trap in the Transmitted Bar for Compressive SHPB

This momentum trap is the most common one used in many labs. In this case, the momentum of the transmitted bar in the compressive SHPB (incident bar in case of tensile SHPB) is transferred to a transfer bar which then transfers it to a momentum trap bar made of brass which is supported on a solid fixture. The energy of the momentum trap bar is absorbed by either a viscous damper or rubber inserts. In this case the energy is absorbed through a rubber insert surrounding the momentum trap bar as shown in Figure 9. The length of the momentum trap bar can be of 150mm or higher. The transfer bar can be 200mm or higher

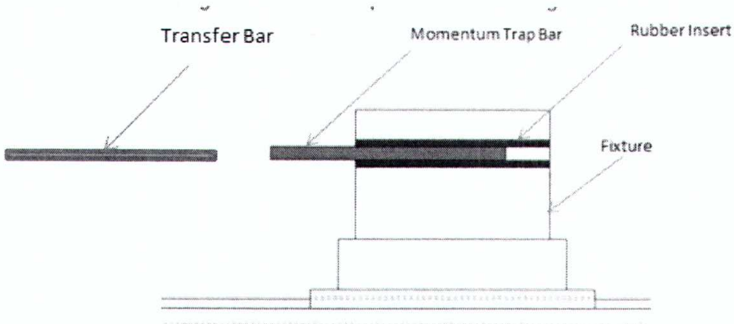


Figure 9: Momentum Trap in the Transmitted bar for Compressive SHPB

3.4.7 Design of Momentum Trap in the Incident Bar for Tensile SHPB

Same as 3.4.6.

3.5 Design of mounting blocks

Since the L/D ratio in the tensile bar is higher than 100 and near 100 for the tensile bar, Mounting Blocks along with Brass Sleeves should be provided for low friction movement of bars during impact and also to prevent buckling.

3.5.1 Mounting Block Supports length for the compressive bar

1	Minimum of Four supports are provided for the compressive bar.	N=4
2	Therefore Length of the Bar L	L=1.6m
3	The distance between the bearings or effective distance leff is calculated as [10]	leff= L/sqrt(N^2-1). = 0.413m

Therefore, the two free ends at both sides l_{free} are of length =0.5*(1.6-3*0.413) =0.1805m.

Figure 10 shows the position of the mounting blocks.

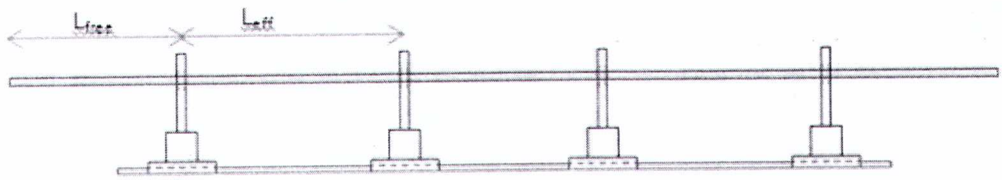


Figure 10: Position of the Mounting blocks in compression bar

3.5.2 Mounting Block supports length for the tensile bar

1	Minimum of Three supports are provided for the tensile bar. Therefore	N=4
2	Length of the Bar L	L=2m
3	The distance between the bearings or effective distance leff is calculated as [10]	leff= L/sqrt(N^2-1). = 0.516m

Therefore, the two free ends at both sides are of length =0.5*(2.0-3*0.516) =0.226m

Figure 11 shows the position of mounting blocks in tension bar.

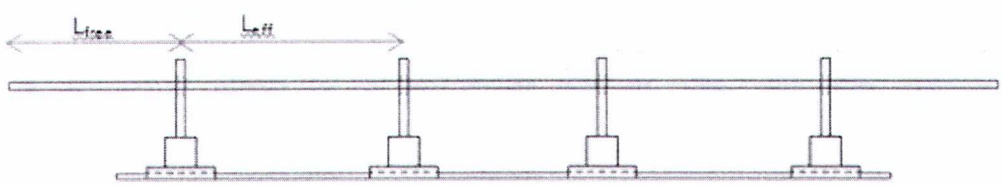


Figure 11: Position of the Mounting blocks in Tension bar

3.6 Design of Bed

The following are the requirements of the Common Bed for the tensile and compressive SHPB

a) Boxed metal Fabricated Base Structure which is stress relived to achieve greater stiffness for high energy impacts. These impacts are caused mainly by 1) The hitting or impact of the transmitted bars (incident bar in case of tension SHPB) on the momentum trap and 2) The recoil of the barrel due to the shooting. Since in both the cases, forces are not very high, a mild steel structure which is stress relieved would be enough.

b) The bed should be such that the Panels & Accessories can be mounted underneath the base for easy access

c) The most important requirement for the base, which is over the table or bed is that it should be aligned accurately. The bar holders can be slided over the bed and should be fixed wherever desired. Therefore, the tolerance of 0.1mm/m throughout the length of base is a must.

d) Levelling Screws should be provided for the legs of the bed/table to maintain flat profile. Figure 12 and 13 shows the bed with the Compressive and tensile SHPB with all other components.

3.7 Design of Specimen Holders for Tensile Setup

Serrated Slots should be provided on the incident bar end and transmitted bar start as shown in Figure 12 so that they can be clamped on both sides. This type of holder is designed to work for both metals, composites and other polymers. The clamps provided the manufacturer should work for all the materials described and it should be checked by the manufacturer through their own testing.

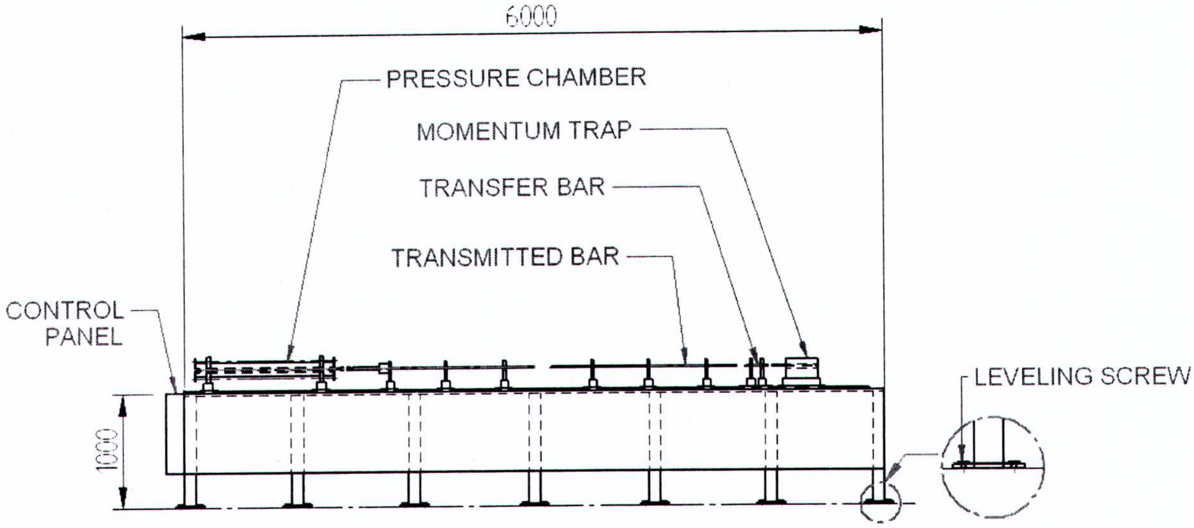


Figure 12: The Bed with the compressive SHPB

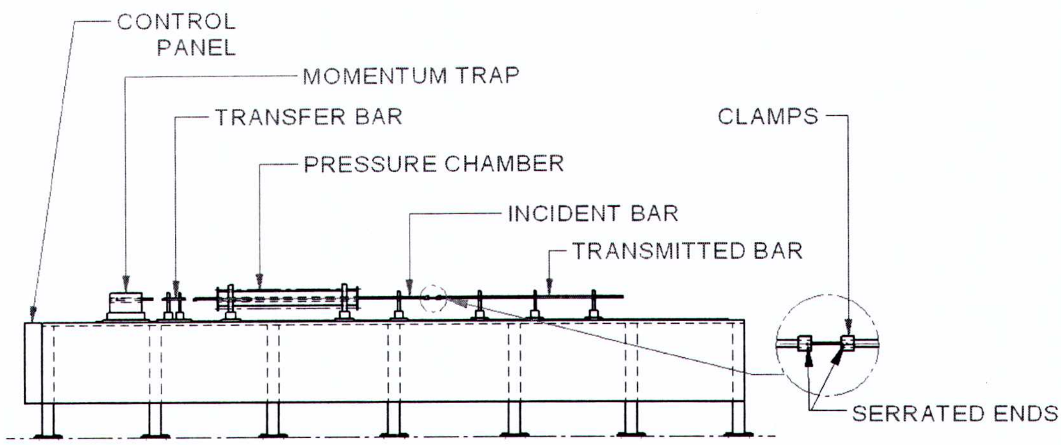


Figure 13: The Bed with the tensile SHPB

4 Maximum Strain Rate Determination for both Bars

Here we are estimating the maximum possible strain rate for the bars designed so far

a) Maximum Possible Strain rate for the Compression Bar

Assuming the reflected wave velocity as one third of the maximum velocity, i.e. Vr =84/3= 28m/s, and sample thickness or length (Ls)as 6mm

The maximum possible strain rate is therefore =2Vr/Ls= 56/(2x10^{-3}) =9000/s

b) Maximum Possible Strain rate for the Tensile Bar

Assuming the reflected wave velocity as one third of the maximum velocity, i.e. Vr =84/3= 28m/s, and sample thickness of length (Ls) as 8mm

The maximum possible strain rate is therefore =2Vr/Ls= 56/(5x10^-3) =7000/s

5 Stress Determination Components for the Integrated SHPB

The basic stress determination components of the SHPB, which are also the electronic components is used for determining the stress-strain relation for the material tested. Usually, the stress and strains in the material tested are determined by the strain gauge values in the incident and transmitted bars. The strain gauges are generally of 5mm gauge length or lesser. A Wheatstone's bridge is necessary to process the strain gauge values. Since the output from the bridge is very small, about a few millivolts, an amplifier is generally used to get higher voltage. The amplifier values are generally taken or read in an oscilloscope or a high speed A/D computer board. The minimum frequency response or bandwidth of the Amplifier should be 100 kHz [9]. The sampling rate at which data is acquired in the oscilloscope should be higher than 1Msamples/Sec. There are 3 Vishay 2310b strain gauge amplifiers presently with us which meets the requirement and has 125kHz bandwidth which is higher than 100kHz. The Vishay 2310b amplifiers are used across the world in many renowned labs and universities for the strain gauges in the SHPB setup. There is also a High Bandwidth (500MHz), Agmatel 3054A Digital Storage Oscilloscope which can store 2000 points. But, since the amplifiers are barely sufficient, few more amplifiers need to brought along with a better high points storage (greater than 2000 points) oscilloscope.

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7 Tables for Assessing the Age and Strain Rate of the bars

1. Life Cycle Estimation for Bars and Strikers

Material		Velocity of striker 84m/s (stress=1650MPa)	Velocity of striker 42m/s (stress=825 MPa)
Maraging Steel	Fatigue life of the Bars (from Figure 7 for unnotched specimen and R=0.02)	10^4 Cycles (approximately 10 years with 1000 tests per year)	>10^6 Cycles
	Fatigue Life of the Strikers (from Figure 7 for unnotched specimen and R=0.02)	10^4 Cycles	>10^6 Cycles
	Fatigue life of the Bars (from Figure 7 for unnotched specimen and R=-1)	8000 Cycles (approximately 8 years)	>10^5 Cycles
	Fatigue life of the Strikers (from Figure 7 for unnotched specimen and R=-1)	8000 Cycles (approximately 8 years)	>10^5 Cycles
Aluminium 7075 T6		Velocity of striker 70m/s (stress=503MPa)	Velocity of striker 35m/s (stress =250 MPa)
	Fatigue life of the Striker (R=-1)	10000 cycles (approximately 10 years)	10^5 cycles (approximately 100 years)
	Fatigue life of Bars (R=-1)	10000 Cycles (approximately 10 years)	10^5 cycles (approximately 100 years)

2. Lowest Maximum Strain Rate estimation for different velocities assuming maximum reflected wave Vr= 0.2Vst which can happen for very hard material. The thickness is assumed as ls= 4mm for both the tension and compression bar.

	Vstriker =84m/s	Vstriker =42m/s	Vstriker = 21m/s
Max Strain rate =2Vr/ls	8400/s	4200/s	2100/s

8 Calibration test for the Split Hopkinson Bar

Check for Alignment of the Bars

The most important calibration required is to check the alignment of the bars with each other and with respect to the striker. This is crucial for obtaining good and reliable results from the test.

There are two calibration procedures, i.e. bar apart testing and bar together testing (M.A. Kariem 20123) in this regard

1) The bar apart testing is performed by using the striker and incident bar only to obtain a correction factor of strain, i.e. the magnitude of theoretical strain (V/2C) divided by measured strain. In this case the velocity V is measured experimentally and then the value of V/2C, where C is the wave velocity of the bar is checked with the strain value. If the maximum strain is closer to this value, then the striker and incident bar is aligned.
2) The bar together testing is performed by using the striker, the incident, and the transmitter bars. This procedure is carried out to obtain correction factor of the stress. i.e. the ratio between the transmitter and incident wave. The incident and transmitted bars are joined and the striker is made to hit the incident bar. The value of strains are noted in the incident bar and their ratios are calculated. A ratio closer to 1 shows good alignment.

Results of these two calibration tests are use to indicate the alignment of the bars.

9 Summary of the design details

A). Barrel Details:		
1	Material	EN8 with yield of 280 MPa
2	ID	32mm
3	OD	42mm
4	Thickness (mm)	5mm
5	Length(m)	1.2m
6	Teflon sleeve inside barrel	ID 16mm/OD 32mm/Length 1.2m to accommodate strikers of 16mm dia with slip fit.

The requirements for the barrel.

a) Digital Pressure Monitoring System for monitoring the pressure in the system

b) Vents for safe release of pressurized gas. These Vents should be provided at the end of the barrel length, so that the velocity of the striker shouldn't change after it has crossed the vents and should be constant when it hits the incident bar.

c) Solenoid valve for pressure control/switching. This will also aid in quick release of the pressure and result in larger velocity of the bar and the arbitrariness of manually releasing the pressure is eliminated and greater control of the velocity is obtained. But it should be made sure that there should not be interference of the solenoid switching on the strain values and if unavoidable it should be such that it can be filtered out.

d) The end of the barrel should accommodate the incident bar when it is used for the tensile setup and it can be completely closed when used for the compressive split Hopkinson bar.

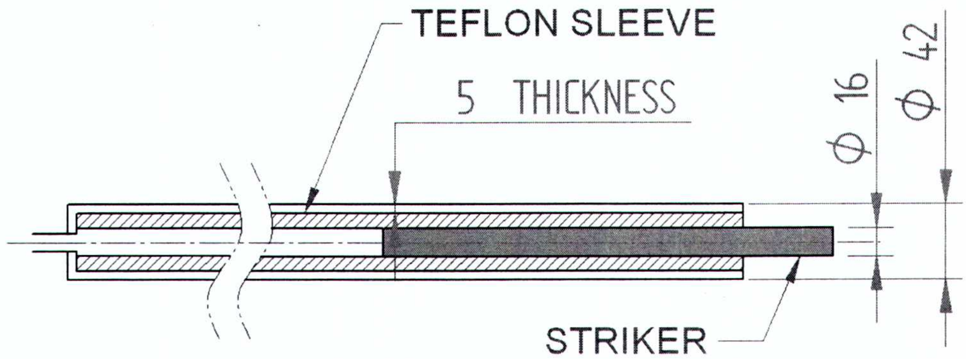


Figure 5 Teflon Sleeve for accommodation of a 16mm diameter striker inside the barrel.

B). Strikers for the Integrated Compressive and Tensile Split Hopkinson Bar :		
1	Material	Maraging steel c250 material
2	Compression SHPB Diameter	16mm with slip fit with the barrel or sleeve
3	Tensile SHPB hollow striker	ID 16mm/OD 23mm with slip fit with incident bar and barrel/sleeve
4	Compression and Tensile SHPB Strikers length	200mm, 300mm and 400mm.
5	The maximum velocity limit of striker	79.6m/s

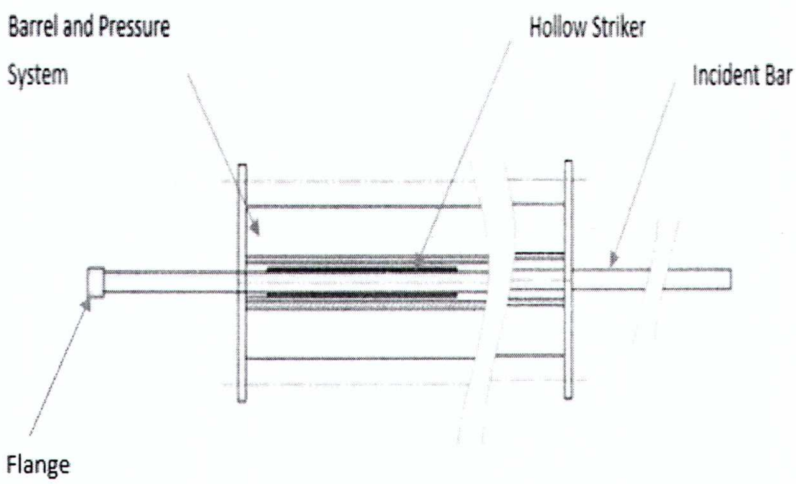
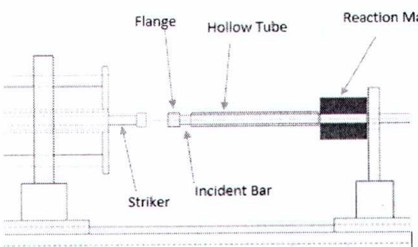


Figure 6:Hollow Striker and the Pressure system within the incident bar in Tensile

Split Hopkinson Bar		
C). Incident and transmitted bars for the Integrated Compressive and Tensile Split Hopkinson Bar :		
1	Material	Maraging steel c250 material
2	Dia in mm (For both compression and tensile SHPB)	16 mm
3	Length of incident and transmitted bar compression SHPB	1600 mm
4	Length of incident and transmitted bar Tensile SHPB	2000 mm (Flange should be provided at the end of incident bar as in fig 2)
D). Momentum Trap for Compressive SHPB for the Integrated Compressive and Tensile Split Hopkinson Bar :		
a)	**Momentum Trap in the Incident Bar for Compressive SHPB**	
 Figure 8 Momentum Trap in the incident bar for Compressive SHPB		It consists of the following other three components apart from the incident bar and a flanged or unflanged striker. 1) Hollow Tube (Maraging steel C250 material) with slip fit. 2) Reaction Mass (With steel block 1 -4kg mass) 3) Flange at the incident of the incident bar 4) All the flanges should be made of same material as the incident and transmitted bar and should be threaded with sufficient length(minimum 30mm) into the incident bar through ASME thread. Flange OD should of dia of 23mm and ID should be 16mm.

b) Momentum Trap in the transmitted Bar for Compressive SHPB

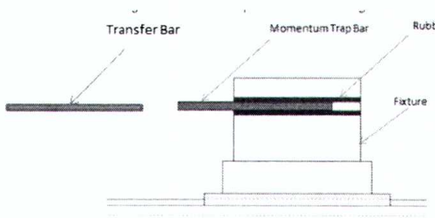


Figure 9 Momentum Trap in the Transmitted bar for Compressive SHPB

a) Material for transfer bar and momentum trap bar Maraging steel C250 and Dia 16mm.
b) Length of transfer bar : Min 200mm
c) Length of Momentum trap bar: Min 150mm

c) Momentum Trap in the Incident Bar for Tensile SHPB (It is as in Fig 9)

D). bearings or mounting blocks for Compressive SHPB for the Integrated Compressive and Tensile Split Hopkinson Bar :

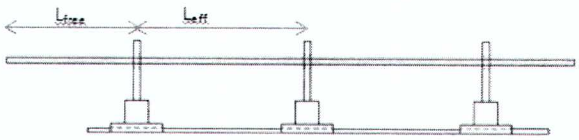


Figure 10 Position of the Mounting blocks

Mounting Blocks along with Brass Sleeves for low friction movement of bars during impact and also to prevent buckling.

Leff 0.3m

E). Design of Bed

The following are the requirements of the Common Bed for the tensile and compressive SHPB

a) Boxed metal Fabricated Base Structure which is stress relived to achieve greater stiffness for high energy impacts which are caused mainly by 1) The hitting of the transmitted bars (incident bar in case of tension SHPB) on the momentum trap and 2) The recoil of the barrel due to the shooting. Since in both the cases, forces are not very high, a mild steel structure which is stress relieved would be enough.
b) The bed should be such that the Panels & Accessories can be mounted underneath the base for easy access
c) The most important requirement for the base is that it should be aligned accurately and therefore the tolerance of 0.1mm/m throughout the length of base is a must and Levelling Screws should be provided for the legs of the base to maintain flat profile. Figure 12 and 13 shows the bed with the Compressive and tensile SHPB with all other

components.

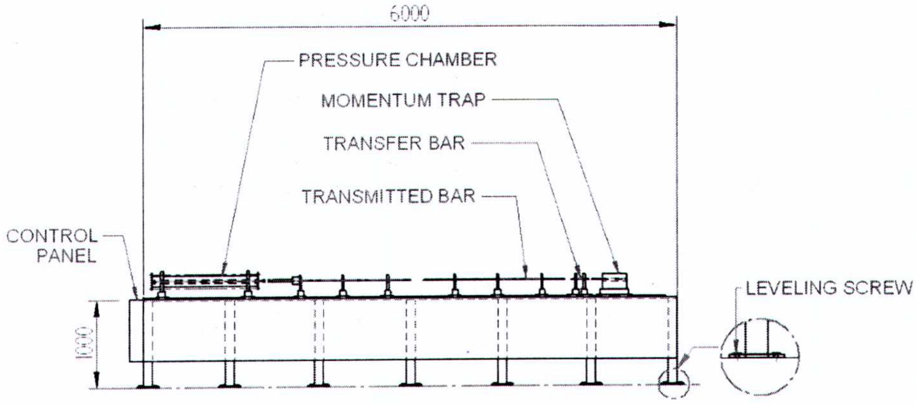


Figure 12: The Bed with the compressive SHPB

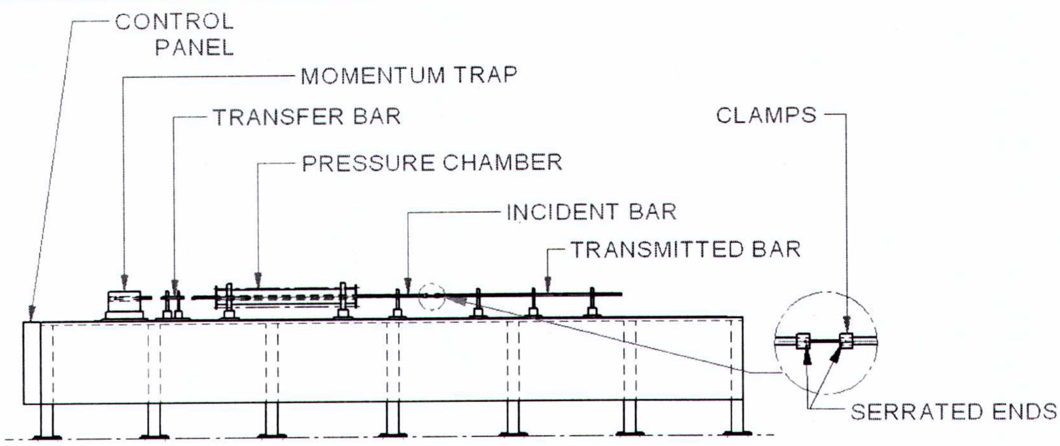


Figure 13: The Bed with the tensile SHPB

F) Specimen Holders for Tensile Setup

Serrated Slots should be provided on the incident bar end and transmitted bar start as shown in Figure 7 so that they can be clamped on both sides. This type of holder is designed to work for both metals, composites and other polymers.

G) Maximum Strain Rate for Both the Bars

1)	Compression SHPB	The maximum possible strain rate is 28000/s with 200 mm striker
2)	Tensile SHPB	The maximum possible strain rate is 11000/s with 200 mm striker

BID-SECURING DECLARATION FORM

Date: ___________________

Bid No. _________________

To (insert complete name and address of the purchaser)

I/We. The undersigned, declare that:

I/We understand that, according to your conditions, bids must be supported by a Bid Securing Declaration.

I/We accept that I/We may be disqualified from bidding for any contract with you for a period of one year from the date of notification if I am /We are in a breach of any obligation under the bid conditions, because I/We

(a)	have withdrawn/modified/amended, impairs or derogates from the tender, my/our Bid during the period of bid validity specified in the form of Bid; or
(b)	having been notified of the acceptance of our Bid by the purchaser during the period of bid validity (i) fail or refuse to execute the contract, if required, or (ii) fail or refuse to furnish the Performance Security, in accordance with the Instructions to Bidders.

I/We understand this Bid Securing Declaration shall cease to be valid if I am/we are not the successful Bidder, upon the earlier of (i) the receipt of your notification of the name of the successful Bidder; or (ii) thirty days after the expiration of the validity of my/our Bid.

Signed: (insert signature of person whose name and capacity are shown)
in the capacity of (insert legal capacity of person signing the Bid Securing Declaration).

Name: (insert complete name of person signing he Bid Securing Declaration)

Duly authorized to sign the bid for an on behalf of: (insert complete name of Bidder)

Dated on _____________ day of ___________________(insert date of signing)

Corporate Seal (where appropriate)

Note:

1. In case of a Joint Venture, the Bid Securing Declaration must be in the name of all partners to the Joint Venture that submits the bid.
2. Bid Security declaration must be signed in by the Proprietor/CEO/MD or equivalent level of Officer of the company.