Needs Assessment and Project Scope

EML 4551C – Senior Design – Fall 2011 Deliverable

Group # 1

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Air Bearing Upgrade for the Split-Hopkinson Pressure Bar Experiment

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Reviewed by Advisor:

Needs Assessment

Warhead design engineers and material scientists require mechanical property information under high deformation rates of loading on a wide variety of materials that have military significance. The most generally accepted technique for gathering such information is the SHPB experiment. The Air Force Research Laboratory's Damage Mechanisms Branch has operated such an experiment for approximately 30 years. The Damage Mechanisms Branch has a requirement to replace the current bearing system with a new air bearing design.

Project Scope

Problem Statement

The goal of this project is to upgrade the current bearing system located on the Split-Hopkinson Pressure Bar experiment in the Air Force Research Laboratory's Damage Mechanism Branch at Eglin AFB to a system utilizing near-frictionless air bearings.

Objectives

The most crucial objectives of this project are as follows:

1. Analyze the engineering challenge of upgrading the Eglin AFB SHPB to a physical architecture based on the use of air bearings.
2. Provide analysis of air bearing hardware cost, interface requirements, installation procedures and impact on the bar geometry.
3. Provide an assessment of strain gauge technology.
4. Develop a procedure to align the bars based on the new architecture.

Other objectives of the project are the acquisition of suitable bearings and related equipment, the installation of the new bearing system on the SHPB, and the initial testing of the SHPB.

Justification and Background

In 1914, Bertram Hopkinson came up with a way to use a metal bar to test stress pulses. H.Kolsky, in 1949, used Hopkinson's idea and expanded upon it. He devised an experiment using two collinear bars to measure stress and strain through a pressure wave, known today as the split-Hopkinson pressure bar experiment.

In this experiment, a specimen is placed between the two collinear bars, transmitted bar and the incident bar, that are placed in a certain number of bearings and are equipped with strain gauges placed on them at specific locations. A device at the opposite end of the incident bar is used to set the bar in motion, creating an incident wave. The bar forces into the specimen, which pushes the transmitted bar into a shock absorbing barrier. The incident wave that is generated goes through the incident bar to the specimen where it is split into two waves before it reaches the specimen. The transmitted wave goes through the specimen, plastically deforming it, while the reflected wave reflects from the specimen back through the incident bar. The stress and strain of the deformed specimen can be calculated using the information collected from the strain gauges.

The Split Hopkinson Pressure Bar, also called the Kolsky Bar is a device used to determine material properties such as stress-strain behavior. The setup consists of two metal bars, the incident bar and the transmitted bar, in which a material sample is placed in between.

The bar diameter can vary in size. A bar diameter of 5/8 in. will be used at the Eglin Air Force Research Lab which is for the purpose of this senior design project. A stress wave is propagated and measured through the bar and the specimen. It is important that the bars are precisely aligned. This will be a critical task that must be conducted for the apparatus to work properly. The Split Hopkinson Pressure Bar device is always mounted onto a sturdy base. The bar setup at the Eglin Research Lab is mounted to an I-beam.

At certain locations along the Hopkinson bar are several air bearings. The project involves the upgrade of new air bearings to replace the current bearings on the bar at Eglin. The air bearings provide a thin pressurized air film that is nearly frictionless in which the bars can easily move. There must be a tolerance between the bearing and the bar, so that the bar will not be hindered from moving. An air supply tube will distribute air to each bearing. The placement of the air bearings cannot interfere with the strain gauges. The spacing of the bearings and the gauges will be determined through analysis from both previous experiments and experiments that will be performed.

Mathematics:

For the design of any engineered metallic item in which the behavior of the material under static or dynamic loading is significant, a statistically relevant reproducible trend. To begin, the force applied has to be standardized through a force/material density. Assuming the force is only in one direction, the stress through a unit of area is given as:

$$\sigma = F/A$$

where σ = stress F = force and A = instantaneous area

In cases of loading where the change in the length of the material under loading is needed the change in length is given as a percentage of the initial length as:

$$\varepsilon = (Li - Lo) / Lo$$

where ε = strain Li = instantaneous length Lo = initial length

The SHPB experiment loads three piece of metal in two different ways. The incident and transmitter bar are loaded elastically. See the SHPB section for more detail. That is the loading occurs and the material stretches or compresses and then after the loading ceases, the material returns to its original length, with no permanent crystal deformation, or “slip” along the microscopic planes of atoms. The point at which the material begins to permanently deform is called the yield point. Inside of the elastic region of deformation the relationship between stress and strain is linear. The ratio of this relationship is specific to each material. This ratio is called the Young’s Modulus E given as:

$$\sigma = E * \varepsilon$$

This elastic behavior is necessary for the SHPB experiment to be quantified. The measurement taken from each of the elastically loaded bars is the strain ε. The strain is measured by a strain gauge. A strain gauge uses the physical changes caused by strain to be measured as a change in resistivity in a resistor set. The strain gauge has a ratio of the change in resistance divided by the strain passing through the material being tested. This ratio is called the gauge factor and is given as:

$$GF = [(Ri - Rg) / Rg] / \varepsilon$$

Where GF = gauge factor Ri = instantaneous resistance Rg = initial resistance and ε = strain

So therefore if the desired strain at a given time is desired, one can rearrange the equation to be:

$$\varepsilon = [(Ri - Rg) / Rg] / GF$$

Where GF = gauge factor Ri = instantaneous resistance Rg = initial resistance and ε = strain

This allows the strain to be the output of the given input of Ri from the resistor set.

The Resistor set is based on a Wheatstone circuit. This circuit allows for precise measurements of the resistance inside of the stress gauge resistor. The Wheatstone circuit contains four resistors, three of which have resistances of known value, and one is the stress gauge resistor. The relationship between them is as follows

$$Rg = (R2 / R1) * R3$$

Where Rg = stress gauge resistance and R1, R2 and R3 are known resistances.

The voltage difference between the two interior junctions is the measured output. The governing equation is given as follows:

$$Vg = [(Rg / \{R3 + Rg\}) - (R2 / \{ R1 - R2\})] * Va$$

Where Vg = measured voltage Rg = stress gauge resistance R1, R2 and R3 = known Resistances and Va = applied voltage

This instantaneous strain is recorded with respect to time. This measurement is taken in two places: The incident bar and the Transmitter bar. The gauges give three strain wave measurements: 1) an Incident wave through the incident bar ε_I 2) A reflected wave through the incident bar ε_R and 3) An incident wave through the transmitter bar ε_T. Given that the initial length of the specimen, and the speed of sound through the specimen material are known, then both the average engineering strain rate as well as the total strain can be calculated using the following equations:

$$d\varepsilon_{avg} / dt = (C_b / L_s) * (\varepsilon_I - \varepsilon_R - \varepsilon_T)$$

where $d\varepsilon_{avg} / dt$ = average engineering strain rate and L_s = initial length of the specimen.

$$\varepsilon_s = (C_b / L_s) * \int_0^t [(\varepsilon_I - \varepsilon_R - \varepsilon_T) * dt]$$

where ε_s = strain in the specimen

As discussed before the strain must have a corresponding stress to allow for computation of the Young's Modulus. The stress at the connection between the incident bar and the specimen is given as a ratio of the area of the two bars (as energy is conserved, the force that is transmitted through the large area of the incident bar must be transmitted into the small area of the specimen) the Young's modulus of the Incident bar and the Incident and Reflected waves as:

$$\sigma_1 = (A_{\mathbf{B}} / A_s) * E_B * (\varepsilon_I + \varepsilon_R)$$

The stress at the connection between the specimen and the transmitter bar is similar to before, but only the transmitted wave is taken into account as:

$$\sigma_2 = (A_{\mathbf{B}} / A_s) * E_T$$

From this the average stress can be taken:

$$\sigma_{avg} = 0.5 * (\sigma_1 + \sigma_2)$$

The elastic strain energy in the incident bar due to the incident wave is given as :

$$E_I = 0.5 * A_B * C_B * E_B * T * \varepsilon_I^2$$

Where E_I = strain energy due to the incident wave A_B = cross sectional area of the bar C_b = Speed of sound in the bar T = amount of time the square loading wave was applied through the gauge.

The elastic strain energy is the same for the reflection and transmitted wave:

$$E_I = 0.5 * A_B * C_B * E_B * T * \varepsilon_R^2$$

$$E_I = 0.5 * A_B * C_B * E_B * T * \varepsilon_T^2$$

The strain energy used in the deformation of the specimen is given as

$$\delta S_E = E_I - E_R - E_T$$

The Kinetic energy is the energy of motion. The kinetic energy being transmitted by the waves are given as:

$$K_I = 0.5 * \rho_B * A_B * C_B^3 * T * \varepsilon_I^2$$

$K_R = 0.5 * \rho_B * A_B * C_B^3 * T * \varepsilon_R^2$

$K_T = 0.5 * \rho_B * A_B * C_B^3 * T * \varepsilon_T^2$

The strain energy used in the deformation of the specimen is given as:

$\delta K_E = E_I – E_R – E_T$

The total deformation energy in the specimen is given as:

$E_s = 2 * \delta K_E = 2 * \delta S_E$

Strain Gauges:

The strain gauges used in the SHPB experiment are electrical resistance gauges. They use the physical distortion in the width of the electrical conductors. The thinner the conductor becomes the more resistance it creates. The thicker the conductor becomes, the less resistance it creates. The placement of the strain gauge is such that as the material being tested is put into tension, the lengths of the gauge are being stretched and as such the resistance increases. If the material is put into compression, then the lengths of the gauge are being shortened and as such the resistance decreases.

The strain gauge has a ratio of the change in resistance divided by the strain passing through the material being tested. This ratio is called the gauge factor and is given as:

$GF = [(Ri - Rg) / Rg] / \varepsilon$

Where GF = gauge factor Ri = instantaneous resistance Rg = initial resistance and ε = strain

So therefore if the desired strain at a given time is desired, one can rearrange the equation to be:

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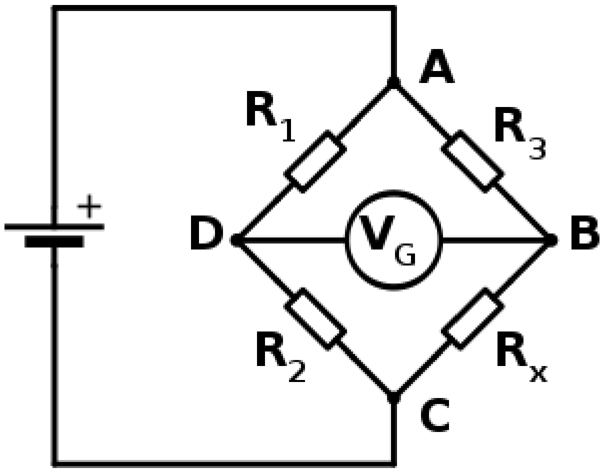
This allows the strain to be the output of the given input of Ri from the resistor set.

The Resistor set is based on a Wheatstone circuit. This circuit allows for precise measurements of the resistance inside of the stress gauge resistor. The Wheatstone circuit contains four resistors, three of which have resistances of known value, and one is the stress gauge resistor. The relationship between them is as follows



Rx = (R2 /R1) *R3

Where Rx = stress gauge resistance and R1, R2 and R3 are known resistances.

The voltage difference between the two interior junctions is the measured output. The governing equation is given as follows:

Vg =[(Rg / {R3 + Rx}) - (R2 / { R1 - R2})] * Va

Where Vg = measured voltage Rx = stress gauge resistance R1, R2 and R3 = known Resistances and Va = applied voltage

Methodology

The first step in the completion of this project will be the research of the history and current state of SHPB devices. Specifically, the workings and mathematics of the design must be fully understood before a suitable design involving air bearings can be implemented. Simultaneously, the team must carry out research into the types, limitations, uses, and manufacturers of air bearings. This will be needed so that when a sufficient amount of knowledge of the SHPB system has been gained the group may quickly progress to determining which bearings will be the most appropriate and placing orders for those bearings and other required equipment. The initial phase of the project will be completed when the requirements for the installations of the new air bearings and a comprehensive approach to support their installation has been detailed for the AFRL. The second phase of the project involves supporting the installation of the air bearings, alignment of the SHPB's bars, test diagnostics, and the initial checkout testing of the final setup.

Constraints

As in any engineering endeavor, constraints are applied so that the project is created as the customer intends. In terms of this project, there are a handful of constraints that are to be kept in mind to make the best product capable.

- Time is to be kept in close mind throughout the entire process from research to the end product. As with all projects, everything is to be completed in a timely manner so that the customer is able to receive their finished product in a desired amount of time to begin use. With this project, the fall semester is to be used to do all of the brainstorming, research and calculations and gaining of fundamental knowledge needed for the end result. The spring semester is to be used for the production of a small scale split-Hopkinson pressure bar experiment.

- The entire project is to be completed within a specified budget to ensure cost efficient large scale production.
- Schedules are to be created and abided by to keep the project flowing as smoothly as possible. Inter-team communication is important so that each member knows their duty and is able to complete it by the given deadline. Outer group communication is crucial to the completion of the project and should be done in a professional manner.
- Eglin Air Force Base has a working split-Hopkinson pressure bar experiment, whose information is vital to the completion of this project. As a group, it will be necessary to make a set number of trips to the Air Force Base in order to gain first-hand knowledge needed for the new design.
- It is important to order necessary parts in a timely manner to avoid last minute building of the prototype. All orders and parts to be machined will need to be assessed in the fall semester.

Expected Results

By the end of the project, the group will be expected to have done the following:

1. Determined what was required to install the air bearings.
2. Provide a detailed engineering approach to support the installment and use of the bearings.
3. Support the installation of the air bearings.
4. Support the alignment of the bars.
5. Support the initial test diagnostics of the system.
6. Support the initial checkout testing of the system.