Tensile Hopkinson Bar Testing of Plastic Films at High Strain Rates

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**Introduction**

This project involves determining plastic film properties during fast loading. Material behavior changes dramatically as the strain rate increases.

Previous research in metals indicates that a significant increase in stiffness occurs during fast loading. While previous research certainly has tested plastics, this research considers thin plastic films under tensile loading. There was no previous research on tensile Hopkinson bar testing of thin plastic films. This project required the development of two separate systems: the air gun system and the measurements system.

**Theory**

The plastic films are tested at high strain rates using a split Hopkinson tension bar. The Hopkinson bar consists of two bars, incident and transmission, joined axially by the plastic film specimen. A high velocity striker bar impacts the incident bar creating a tensile pulse. When the pulse reaches the film, part of the pulse travels through the plastic film and part travel back into the incident bar. Similarly, the pulse travels into the transmission bar from the film specimen. Strain gages located on the incident and transmission bars record the strain as the pulses travel through the bars. Pulse magnitude and timing analysis determines the plastic film properties. Al-Mousawi, Reid and Deans (1997) give a good derivation of the relevant physical and mathematical models.

Using a hollow bar increases the pulse magnitude and allows for a more sensitive measurement system. Chen, Zhang and Forrestal (1999) provide a Hopkinson bar derivation based on hollow bars.

**The Air Gun**

The air gun consists of the air chamber, valve assembly and striker bar. The air gun propels the striker bar, which creates a tensile pulse. A schematic view is given in Figure 1.

![Figure 1. Air Gun Schematic](image-url)

Figure 1 shows the general layout of the air gun and the Hopkinson bar. Firing the air gun requires 3 steps: loading, pressurizing and firing.
Load the Striker Bar

The striker bar must be seated at the air gun’s breech. This is accomplished by pushing the striker bar up the muzzle. Figure 2 shows the beginning of a loading process.

![Figure 2. Air Gun Muzzle](image)

As seen in Figure 2, the striker bar is flush with the muzzle end and is ready to be pushed into the gun. If the striker bar sticks a few inches into the bore, the striker bar has been locally deformed at the striker bar-striker plate interface. To fix this deformation will probably require machining.

The bar will seat at approximately 11 inches from the muzzle end. The bar must be firmly seated or the bar will move forward while filling the air chamber. Do not load the striker bar while the air chamber is pressurized.

Pressurize the Air Chamber

Filling the air chamber requires synchronized and timely operating of valves. Figure 3 shows the valve setup.

![Figure 3. Air Gun Valves](image)
First, the exit valve is closed and the inlet valve opened. The chamber will emit a clunk as an internal valve seats. The chamber will start filling. After the chamber pressure exceeds the specific test pressure, close the inlet valve. Because of leakage, the chamber pressure will start decreasing.

**Fire the Air Gun**

When the chamber pressure bleeds down to the proposed test pressure, quickly open the exit valve. The air gun should fire. If the gun only hisses, the exit valve was opened too slowly.

**Plastic Film Holders**

The film holders perform a difficult job. They must securely hold the plastic films while transferring the tensile pulse. I used plastic holders as shown in Figure 4.

![Plastic Film Holders]

**Figure 4.** Plastic Film Holders

The holders are made from a brittle plastic. The perpendicular restraint rods are used to wind up the plastic film into the C channel. I added a black plastic block to assist the winding process. Without the black blocks, the winding process required at least one hour instead of the current 5 minutes.

**Kodak Plastic Film**

Kodak photosensitive plastic film was used. The four-thousandths thick film was cut to 0.5 inches wide. Each film test section was cut to 4.5 inches long. After rolling into the holders, the exposed test section was 1 inch long.

**Measurements**

The measurement system is the most critical part of this project. The system must measure small pulses traveling at high speeds. Additionally, the system must scan at a high rate. These requirements meant using a computer acquisition system and sensitive
transducers. I considered two transducer systems: strain gages and piezoelectric crystals. Because of availability, I used strain gages.

**LabView**

The digital acquisition and computer system gathers and reports the experimental data. A National Instruments SC 2043 board combined with a PC running LabView provides the data gathering and reporting. Figure 5 shows the general acquisition setup.

![Acquisition System](image1)

**Figure 5.** Acquisition System

As Figure 5 shows, strain gages were connected to the acquisition board. Both bars were measured with strain gages. The board was configured to measure a quarter bride strain gage system. From the SC-2043 manual, Figure 6 shows the electrical schematic used for each strain gage.

![Quarter-Bridge Strain Gage Schematic](image2)

**Figure 6.** Quarter-Bridge Strain Gage Schematic

From Figure 6, only one strain gage is used per channel. This setup requires moving several jumpers as given in the SC-2043 manual. Specifically, the source jumpers must be set to internal and the bridge jumpers set to half bridge (W7 and W6). Also, a completion resistor is required in R52 for channel 0 and R36 for channel 1. Jumper W8 must be set to ST.

I created a LabView virtual instrument, .vi, file to setup, measure and record the acquisition board’s output. As the experiment required a fast scan rate of at least 100KHz, a specialized LabView sub-vi file was required. My final virtual instrument is a modified form of the Acquire N Scans.vi given in the ./Labview/examples/daq/alogin/alogin.llb directory. Figure 7 shows the LabView Diagram of my Hopkinson Bar Virtual Instrument.
The diagram shown in Figure 7 provides up to a 1 MHz scan rate with data logging to a file. A chart shows the output of the two channels. Figure 8 shows the virtual instrument face.

When working with the virtual instrument, it is important to set channels to 0,1 and to give a file name in the file path box. The scan rate directly sets the scanning frequency in Hertz.

**Strain Gages**

Strain gages are used to measure the pulse’s magnitude. Strain gages are attached to both the incident and transmission bars. Because the induced strains are small, the measurement system required 1000-Ohm strain gages rather than the common 120 or 350-Ohm gages. I used EA –06-250BK-10C 1000 Ohm strain gages from Measurements Group. These gages have a ¼ inch gage length. The gage was glued to the outer bar surface on both the incident and transmission bars. Wires were soldered to the gages and run to the acquisition board. Because the bar moved, the wires were taped to the bars to prevent the wire from tearing off the strain gages.
**Piezoelectric Measurements System**

A piezoelectric measurement system was investigated to increase sensitivity. The piezoelectric measurements system requires crystals and a charge amplifier. This system has problems with availability.

**Crystals**

The critical part for a piezoelectric system is the piezoelectric crystal. The crystal indicates pressures with a small induced charge. The crystal is used as given in Figure 9.

![Piezo Crystal Measurement System](image)

*Figure 9. Piezo Crystal Measurement System*

The actual crystals must be specifically manufactured. The crystal as used in Figure 9 needs to be an x-cut quartz with the bar’s cross section. Thinner crystals are good for higher frequencies, so the crystal should be on the order of 0.01 inches. Conductive coatings are suggested. Chen, Lu and Zhou (2000) are a good crystal reference. Ed Strepaniski and Larry Linworth are also recommended for crystal references. Their contact information is given in the Contacts section.

I contacted Boston Piezo for pricing and availability. They can make the crystals with a predicted cost of 6 dollars per crystal in lots of 10. Boston Piezo sends the crystals to another company for the conductive coating process, so the total crystal cost will be somewhat higher. Boston Piezo requires 6 to 8 weeks to make a batch of crystals. Adding the conductive coating increases the production time to an estimated 3 to 4 months.

Conductive epoxy is required to join the crystal to the bars. Tra-Con supplied Tra-Duct BA 2902 epoxy sample. This epoxy is normally sold in cases of 25 or approximately $450. I obtained the free samples by talking with Jesse Morrison in the Applications Engineering department. He was interested in the epoxy’s performance for this application.

**Charge Amplifier**

The charge amplifier is required to increase the crystal’s output for measurement. I bought a Kistler 5010B1 charge amplifier. The charge amplifier is shown in Figure 10.
The 5010B1 is a single channel charge amplifier. The input and output are BNC connectors. The input wiring will require shielded cable because of the small charges and moving wiring.

Results

This project’s results were disappointing. Although the Hopkinson Bar was operational, there were problems. The worst problem was that the measurements system sensitivity was too low.

Poor measurements system sensitivity meant that the experiment did not produce loading results. A bending moment test ensured that the system was recording data; however, the pulses were not discernable from the background noise in either the transmission or incident bars. Even if I had used a crystal transducer in the transmission bar, the incident bar would have still required changing.

The plastic film holders were problematic. I broke the holders twice, once at the threads and once at the restraint rod end. The holders were clearly not designed to withstand fast tensile loading. These plastic holders broke at 60 psi, which is only half of the air gun’s tested upper operating pressure. Since they failed, the holders were certainly exhibiting plastic deformation during the test. Also, the holders scratched and delaminated the photosensitive Kodak film used for the tests. Designing a better holding system is prudent, yet inventing a good design still remains. The holders need a better gripping and pulse transmission method.

The project did accomplish several objectives. The air gun worked flawlessly. This certainly validated my overhaul and modification of the air chamber and triggering system. Without a consistently firing air gun, the project could not proceed. The LabView and acquisition board performed according to my expectations. Additionally, my virtual instrument upped the maximum known scanning rate.
Recommendations

I recommend the following:

1. Use piezoelectric crystals as the transmission bar’s measurement system. Strain gages are not sensitive enough.
2. Order the piezoelectric crystals early.
3. Find another piezoelectric crystal distributor if possible.
4. Test the data acquisition system with a signal generator.
5. Develop a triggering system for the measurements system.
6. Use a full Wheatstone bridge for better strain gage sensitivity.
7. Use a smaller strain gage length.
8. Do not attempt to stop the air chamber leakage.
9. The incident bar’s striker plate must be mounted more securely.
10. Align the transmission and incident bars with carbon rod supports.
11. Develop better transmission grips (film holders).
12. Change the incident bar to aluminum or hollow steel.
References


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Measurements Group, Box 27777, Raleigh, NC, Fax 919-365-3945.

Piezoelectric Crystals
Boston Piezo, Tel. 508-966-4988.

K-Tech, (Ed Strepanski), Tel. 505-998-5830.

Panametrics, (Larry Linworth), Tel. 781-899-2719.

Tra-Con, 45 Wiggins Ave., Bedford, MA 01730, Tel. 781-275-6363, Fax 781-275-9249.