Shock Tube for Gas Dynamics and Chemical Kinetics Research

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Introduction

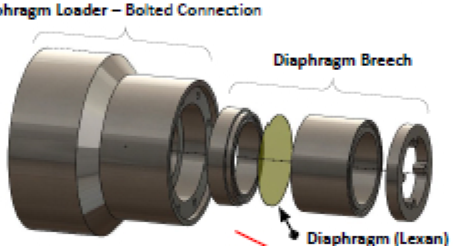
- The Stephen F. Austin State University (SFASU) shock tube is a bursting-diaphragm type with an all stainless-steel construction. The tube is comprised of two sections, the driver and driven section, separated by a diaphragm.
- The driver section is pressurized until the diaphragm breaks. The sudden change in pressure sends a shockwave through the driven section and reflects off the end of the tube creating the desired test region of high temperature and pressure (T_5, P_5).
- Both the driven and driver sections of the tube are mated with a weldless-flange design to allow for consistency of the internal diameter at each connection.
- The SFASU shock tube will allow the authors to study mixtures of various fuels and oxidizers using advanced spectroscopy techniques to develop and test for chemical reaction rate parameters. Shock tubes can generate repeatable conditions of elevated temperature and pressure while maintaining quiescent flow [1].

Configuration

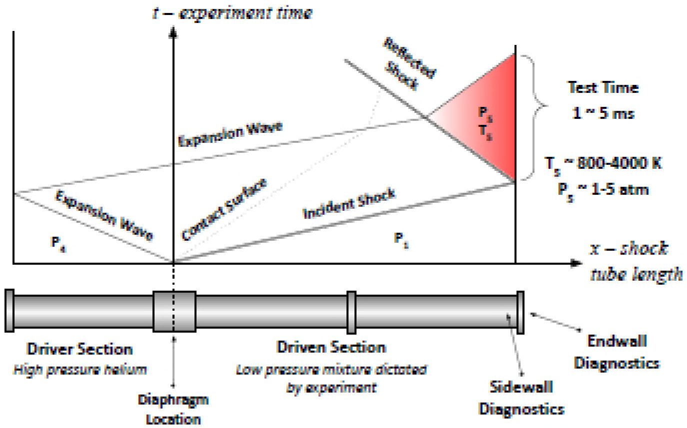
Designed Reflected-Shock Test Conditions:
- $P_5 = 1 - 5$ atm capability
- $T_5 = 800 - 4000$K Test Temperature

Shock Tube Dimensions (Bursting-diaphragm type)
- 2.14 m Driver and 4.28 m Driven Section lengths
- 7.62 cm inner diameter throughout entire tube
- Stainless steel 304 material
- Vacuum o-rings at all connections

Diaphragm Loader:
- Breech-loading design
- Replace diaphragm between each experiment by loading breech



Experiment x-t Diagram



Shock Tube Operation

1. Gases will be mixed in a mixing tank and then transferred to the driven section. The pressure of the gaseous test mixture is labeled as P_1 above.

2. The driver tube is pressurized with Helium until the diaphragm breaks (represented by $t = 0$ on the x-t diagram). The pressure of the driver section before the diaphragm bursts is labeled as P_4. The large pressure differential between the driver and driven sections at diaphragm rupture will send a shockwave through the driven tube.

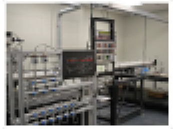
3. The speed of the incident shockwave is measured using calibrated fast-acting pressure transducers in series. This speed is used to determine test conditions, labeled as T_5 and P_5 in above image, from Rankine-Hugoniot 1D shock relations [2].

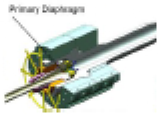
4. Data is taken using spectroscopic instruments and pressure transducers as the shockwave is reflected off the end of the driver tube. Test ends with arrival of expansion wave causing change in flow.

5. Venting and vacuuming shock tube down to replace diaphragm and ready the tube for another shock. Total process takes between 30 to 45 minutes depending on mixture being tested.

Examples of Shock Tubes in Research

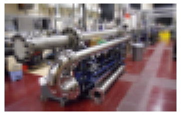
Texas A&M University HPST [3]
- Research group of E.L. Petersen
- Heated to investigate low vapor pressure fuels, ~100 atm capability





Caltech GALCIT T5 Reflected Shock Tunnel [4]
- Research Group of J.E. Shepherd et al.
- High-speed flow can be generated at up to 1000 atm and 10,000 K

Stanford University AST [5]
- Research group of R.K. Hanson
- Pyrolysis and ignition delay times in low-vapor-pressure fuels by creating a fine aerosol in driven section of the shock tube

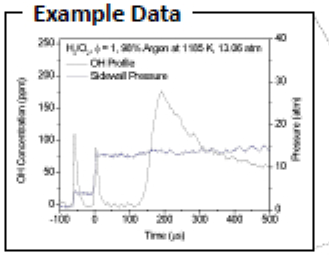


SFASU Shock Tube:
- Focus on chemical kinetics of various fuels and oxidizers as well as gas dynamic formation of shock waves throughout the entire shock tube (with help of 25 access ports for diagnostics)

Future Work for SFASU Shock Tube

- Design of the SFASU shock tube is complete and construction is underway as of Fall 2019
- Initial tests will consist of light emission of simple hydrocarbons to validate with known kinetics mechanisms
- More advanced diagnostics are being developed to measure species profiles through reaction, example work from author shown here [6]:

Example Data



- Blue data trace shows pressure measured in a typical shock tube experiment from sidewall location – note initial and reflected shock

Helium Supply and Vacuum
Helium driver gas plumbing with connection to vacuum system

Mixing and Vacuum System
Plumbing manifold used to generate mixtures for study and to vacuum down tube between experiments

25 access ports along length of shock tube

Weldless flanges for all connections

Time Interval Measurement
Piezoelectric pressure transducers measure shock velocity for use in Rankine-Hugoniot shock equations

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References
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2. John, J.E. and Keith, T.G. (2006) *Gas Dynamics*, 3rd ed., Pearson
3. Aul, C.J., Metcalfe, W.K., Burke, S.M., Curran, H.J., and Petersen, E.L. 'Ignition and kinetic modeling of methane and ethane fuel blends with oxygen: A design of experiments approach', *Combustion and Flame*, 160(7), p1153-1167.
4. Stalker, R.J., Hornung, H.G. et al. T5 reflected shock tunnel. http://shepherd.caltech.edu/T5/facilities/T5/T5.html
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6. Aul, C.J. (2013) *Measuring Hydroxyl Radicals during the Oxidation of Methane, Ethane, Ethylene, and Acetylene in a Shock Tube Using UV Absorption Spectroscopy*. Doctoral dissertation, Texas A&M University.