the Bell Jar

Vacuum Technique and Related Topics for the Educator & Amateur Investigator

Notes from the Vacuum Shack — No. 8 July 2020

In this issue:

- Pulse valves and the automobile fuel injector
- Bruce Kendall on the restoration of antique vacuum equipment
- Some links related to DIY cyclotrons and an "electron mirror"
- Update on the editor's plasma jet apparatus

Pulse Valves and the Auto Fuel Injector

In *the Bell Jar* Volume 10 No. 1/2 (Winter/Spring 2001) I did an article on various types of pulse valve. The concluding section of the article dealt with auto fuel injectors and their application in gas delivery to vacuum systems. Much of the material was drawn from the work of Kendall [1] and Dobson and Kendall [2]. At that time, the dominant models of injectors required a stepped pulse: a high initial current to open the valve and then a lower sustaining current for the balance of the pulse. This function could be provided by either the National LM1949 or the Motorola MC3848 ICs. The stepping is important to keep the coil from burning out. These valves open with a current of 2.1 amps. The control circuitry then quickly drops the current to a sustaining level of about 0.6 amps.

Kendall pointed out a number of features and cautions with the Bosch and Bendix fuel injector valves that he tested when they were used with gases:

- Continued operation at the opening current level will burn out the coil. In normal use the fuel will provide cooling to the solenoid. This is not the case with gases and the coil can burn out in just a few seconds.
- Pulse width, duration and repetition rate may be adjusted to provide the desired flow.
- Operation is generally stable at pulse widths above a few milliseconds. Duty cycles should be below 75%. Pulse repetition rates can be in the hundreds.
- The metallic seat seals in the Bosch and Bendix valves that were tested had leak rates on the order of 10^{-5} to 10^{-6} liters/sec. Open conductance values were on the order of 2×10^{-2} liters/sec at 1 atm. inlet pressure.
- New valves come with a coating of an oily protectant. This has to be removed with solvent prior to vacuum use.

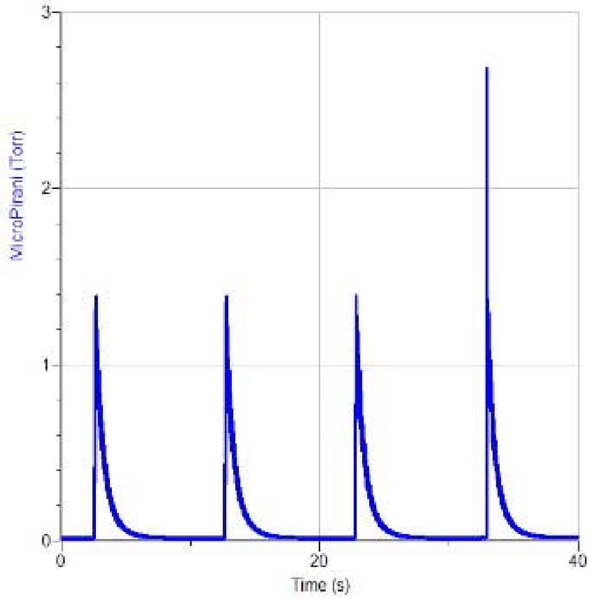
When I reprinted the article in *The Second Five Years*, I had learned that there was also a type of fuel injector that didn't need the current stepping action. These are "high impedance" injectors and they can be differentiated by the coil resistance. The low impedance valves have a solenoid resistance of about 2 ohms and the high impedance ones measure about 12 ohms. I purchased a valve intended for a 4 cylinder Honda Civic and I proceeded to not do much with it except for verifying operation with a simple pulse width modulator board.

This month I dug out the valve and purchased a nice little panel mount timer device from Amazon. This was identified as a Pemenol XY-WJ01. Price was about $16. In my collection of stuff was a nice little box for another project. The box was designed for housing a Drok buck voltage regulator. This came with banana jacks and a cutout for the module. The photograph below shows the timer with the suggested circuit. I had to chuckle at the display shown in the Amazon listing. The manual for the timer is at http://attach01.oss-us-west-1.aliyuncs.com/IC/Datasheet/13339.pdf.

The timer can be set to on/off intervals as short as 0.01 seconds and as long as 9999 minutes. It can run in single shot or continuous modes. I'm skeptical about the low end since the switching is by relay. The relay is a Songle SRD-05VDC-SL-C and the specification sheet shows an operation time of <10 msec and a release time <5 msec. I ended up setting the timer for a 10 second off period and 0.1 seconds on. This is quite conservative for the valve and relay.

I attached the injector to my vacuum stand using a 3/8" tube fitting with a plastic ferrule. The inlet was left open to the atmosphere. The photograph on the next page shows the manifold, isolation valve, timer, power supply set for about 13.8 volts (lead acid battery voltage) and gauge. The gauge is an MKS 925C microPirani. I connected it to a computer running Vernier Logger *Pro* 3 data logging software. Sample rate was 200 per second

The lower part of the manifold is connected to my 3.5 cfm Alcatel (Adixen) 2005SD rotary vane pump. The pumped volume is about 1.1 liters. The plot to the right in the figure shows the pressure response trace with the manifold being pumped. You can clearly see the initial pulse to about 1.4 Torr and the exponential decline back to base pressure. The 4th pulse is with the isolation valve partially closed. I also ran the valve with the isolation valve completely closed. This showed a series of steps of about 10 Torr per step.



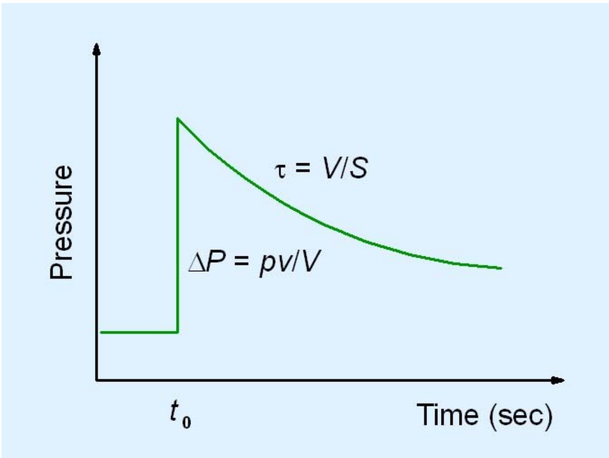
Pulse valve testing. The photograph at the left shows the manifold with butterfly isolation valve, vacuum gauge and fuel injector. The pulse module is at the top. The DC power supply is to the right. The plot to the right shows 4 cycles. The first three are with the isolation valve open. The 4th is with the valve mostly closed.

One application of pulsed valves is in the calibration of RGAs. This is noted briefly in the AVS *Recommended practice for process sampling for partial pressure analysis* [3] and covered in detail by Kendall [1]. The basic idea is to quickly admit a known quantity of gas into a chamber. The gas is expanded into the known volume of the chamber and gives a reproducible and predictable pressure increase.

In this method, a chamber that is continuously pumped has attached to it an RGA and a manually actuated pulse valve of known internal storage volume *v*. With the gas in the pulse valve at pressure *p*, the mass quantity of gas introduced to the chamber is *pv*. (Note that the valve and any connected volume must be isolated.) With the chamber at base pressure, a quick puff of gas is admitted from the pulse valve. The duration of the gas pulse must be shorter than the time constant (τ) of the system. This is determined using the volume of the chamber *V* and the pumping speed *S*. Kendall used pulses on the order of 15 ms for systems with time constants in the range of a few tenths of a second. This is depicted in the figure on the next page.

These valves can also be used as pressure control valves when run at much higher pulse rates. The issue is that, unlike the situation with needle or proportioning valves, the chamber pressure will be “spiky.” Kendall suggested the use of a muffler type device between the valve and the chamber to smooth out the flow.

Next steps will include replacing the relay timer with one using a MOSFET switch, testing with shorter pulses, testing with a high vacuum pump, and some pressure control experiments. One



negative feature of this particular timer is that it is an absolute pain to make adjustments – each setting requires a series of button presses. This is great for “set and forget” and there’s no guessing with regard to the settings. I will be trying a continuously variable (frequency and pulse width) device. One plan is to use the valve for triggering pulsed plasma devices.

As a side note, I came across a paper by Wolf *et al*. [4] where an Arduino was used as a controller for a commercial pulse valve. Coupled to the Arduino was a simple MOSFET driver. The paper includes the code.

References

1. B.R.F. Kendall, *Pulsed Gas Injection for On-Line Calibration of Residual Gas Analyzers*, J. Vac. Sci. Technol. A (1), Jan/Feb 1987.
2. J.L. Dobson and B.R.F. Kendall, *Controllable Leaks Using Electrically Pulsed Valves*, J. Vac. Sci. Technol. A 8(3), May/Jun 1990.
3. James E. Blessing *et al*., *Recommended practice for process sampling for partial pressure analysis*, J. Vac. Sci. Technol. A 25(1), Jan/Feb 2007, pp. 167-186.
4. 4. Margaret Wolf, Veronica Hayes, Cynthia R. Gerber, Philip G. Quardokus, Jose J. Ortiz-Garcia, Casey Plummer and Rebecca C. Quardokus, *Microcontroller design for solution-phase molecular deposition in vacuum via a pulsed-solenoid valve*, J. Vac. Sci. Technol. A 38(2) Mar/Apr 2020.

Restoration of Ancient Vacuum Equipment

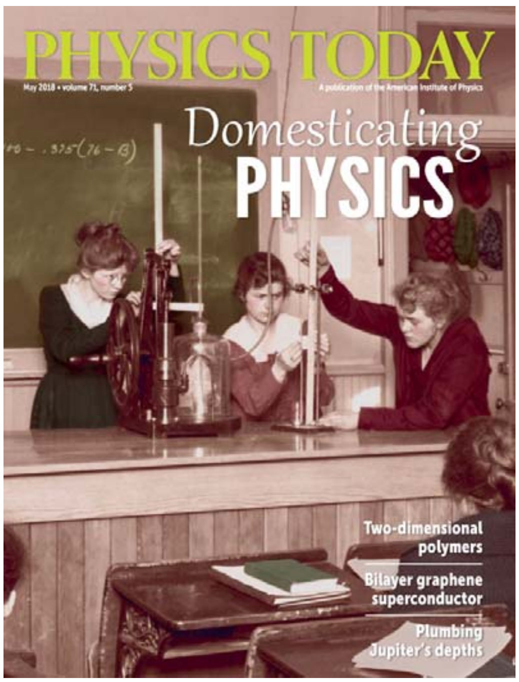
Prof. Bruce Kendall (referenced in the previous article) recently informed me that he is devoting some of his retirement time to restoring ancient vacuum equipment. He writes:

> “You may remember that I used to own a Fleuss rocking-beam piston pump, as shown on the front page of *Physics Today* a couple of years ago in a re-enactment of early vacuum experiments. After dismantling and cleaning it (100 years old oil is like solidified glue) I sold the project to a gentleman named Kim Steiner who modified the interior of the pump to take modern O-Ring seals.
>
> “A condition of the sale was that the final product would be accessible to historians via detailed photographs and other records. Kim has produced an extensive album of photographs of the internal and external structure and I have test data using a rough approximation of the AVS mechanical pump test protocol. An impressive feature for teaching applications is the near-perfect anti-suckback performance, far surpassing most

modern pumps.

“Kim also has a restored 1930s Cenco Hyvac mechanical pump with Emerson electric motor drive.

“It strikes me that restoration of early equipment like this could become an accepted hobby, as well as providing useful equipment for what seems to be a rising tide of vacuum hobbyists.”



The referenced cover photograph was in the May 2018 (Vol. 71, No. 5) issue *of Physics Today* (https://physicstoday.org). The descriptive text for the cover reads:

“In a physics classroom circa 1914, women investigate the effects of pressure to better understand high-altitude cooking. Beginning on page 50, Joanna Behrman explores how household-physics courses that were popular in the early 20th century encouraged female students to make connections between physics principles and domestic tasks. (Image courtesy of the University Historic Photograph Collection, Colorado State University, Archives and Special Collections; colorized by PHYSICS TODAY.)”

For the duration of the COVID-19 event, the content of Physics Today is open to all who register. The article is well worth reading.

DIY Cyclotrons

Scientific American’s “The Amateur Scientist” of September 1953 has an article about the construction of a small cyclotron by a group of high school students. From the article, “A group of teen-agers in El Cerrito, Calif., decided to have one although they knew that even a small cyclotron may cost tens of thousands of dollars and require such finicky adjustments that nuclear physicists sometimes spend months getting the bugs out of it. The boys, lacking the mature judgment that so often prevents adults from having fun, built their cyclotron largely out of junk parts, and it worked fine!”

The group obtained a considerable amount of support for the project, a great example of what a determined group of kids can achieve.

For more recent work, Mark Atherton provided some interesting links.

Leslie Dawan’s bachelor thesis on *Design and Construction of a Cyclotron Capable of*

Accelerating Protons to 2 MeV. This may be found at http://web.mit.edu/ldewan/Public/22thesis/22thesis10.pdf. She also has a very animated presentation that can be viewed at https://www.youtube.com/watch?v=Uvf_z7a-enc

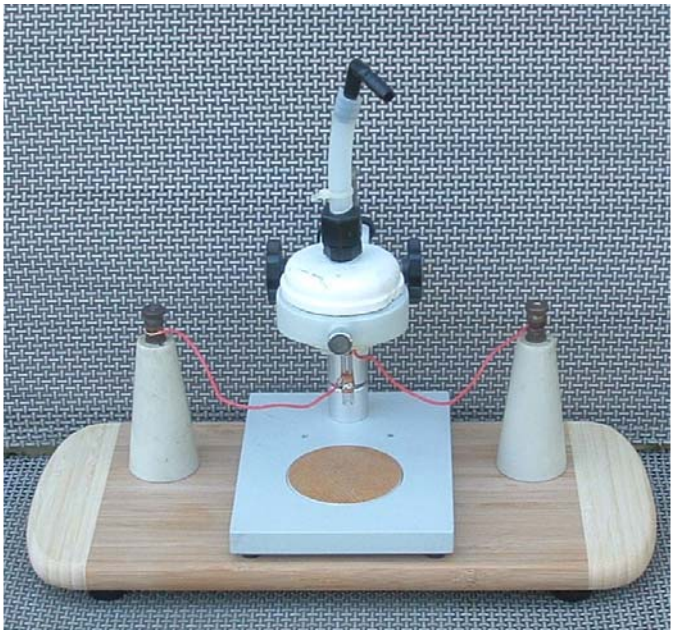
Mark notes that she should have started the presentation by stating that she had implemented the Ernest Lawrence 1923 patent which earned him a Nobel Prize.

Also worth looking at is the site https://thecyclotronkids.wordpress.com/links/ - specifically the *Cyclotron Design Document*.

Not about cyclotron's but Sam Zeloof's "electron mirror" in an electron microscope might be interesting: https://www.youtube.com/watch?v=Z2OYdKb2fpM. Mark notes that Sam has done some other very clever stuff.

Quick Update on My APPJ

Last month I provided some information on my atmospheric pressure plasma jet (APPJ). I improvised the mounting for the photograph. In the intervening month I repurposed a low power microscope stand for holding the device (and any follow-on versions).



I soldered hookup wire leads to the copper foil electrodes. These are connected to 3" tall ceramic insulators. The capillary tubing is held in a Parker P4MC4 polypropylene compression fitting (1/4 tube to 1/4 M-NPT). This, in turn, is threaded into a modified PVC plumbing endcap for 1-1/2 inch threaded pipe. The body of the cap had to be turned down to 2 inches to fit the ring that was originally occupied by the microscope. The base, of course, is one of my signature bamboo cutting boards.

Articles of Possible Interest in *Vacuum Technology & Coating* Magazine

August 2020
High Speed Pulse Valves - Part 1. This covers valve mechanisms and some related applications. The second part (September 2020) will include some details on the reactant delivery systems that use pulse valves for processes such as atomic later deposition (ALD).

August 2009
Vapor Pressure: Working for us or against us? This covers the negative aspects of the vapor pressures of materials in vacuum systems as well as how the vapor pressure characteristics of various process materials (both low and high) are key enablers to a wide number of processes.

Articles may be accessed at http://vtcmag.com/. Scroll to the bottom of the page to the back issue selection box. Looks for my columns and you can probably find other articles of interest in each issue.

End Notes

Next month's issue will have articles on the use of orifices for pressure control and vacuum system diagnostics. I'll be beginning a series on the follow-on to the Vacuum Principles and Applications Laboratory – Advanced (VPAL-A) trainer. This will be the big brother to the BVES trainer. There will also be some further updates on plasma jets, pulse power supplies pseudosparks and whatever else ends up in my inbox.

Steve