# *the* Bell Jar

## Vacuum Technique and Related Topics for the Educator & Amateur Investigator


## Notes from the Vacuum Shack — No. 6 May 2020

**In this issue:**

- Refrigeration service vacuum pump update
- Mark Atherton's single supply thermocouple gauge controller
- Articles of Possible Interest in *Vacuum Technology & Coating* Magazine

### Refrigeration Service Vacuum Pump Update

#### *Introduction*

During April I received an email from Dr. Shawn Carlson. Readers may remember Shawn as the founder and director of the much missed organizations the Society for Amateur Scientists (SAS) and the follow-on Citizen Scientists League. Shawn is still very active in the amateur science arena through his LabRats program [1] and Citizen Scientists' Workshop YouTube channel [2]. He is working on a number of projects involving vacuum and also has received a few inquiries from experimenters that are just getting started in vacuum. Shawn noted that the section on refrigeration service vacuum pumps in the booklet that I prepared for the Citizen Scientists League [3] includes a link to hardware that I no longer supply.

Someday I will get around to updating that booklet but in the interim, here is some guidance on the selection and use of these pumps.

#### *Pump Selection*

When I discovered these pumps (early 1990s), there were only a couple of widely available brands, Robinair and J/B Industries. They could be obtained from dealers in HVAC supplies. These pumps were 2-stage rotary vane pumps with gas ballast, isolation valve and two flare fitting inlet ports. Base pressures were not quite as good as with the industrial grade pumps (10 to 20 milliTorr vs. sub-1 milliTorr) and not designed for continuous service. However, they represented a good value and were entirely satisfactory for a wide range of amateur and educational applications.

In the intervening years, the Robinair and J/B lines have expanded and have been joined by a long, list of Chinese brands. Virtually all of these are available through mail order outlets such as

Amazon and eBay. Now the question is “which ones are most suitable for non-industrial applications?”

For the best utility, the pump should have a free air displacement of from 3-5 cfm, have two stages with a base pressure in the 10-20 milliTorr range and incorporate a gas ballast valve. Having an inlet isolation valve is a plus.

I’ve purchased and specified any number of the Robinair and J/B pumps. The Robinair 15400 (4 cfm) and J/B DV-85N (3 cfm) pumps meet all of the listed attributes. The Chinese pumps are much less expensive but are also a bit less “polished.” That said, I’ve had very good luck with them. One was easily torn down, cleaned and prepped for oxygen service with inert pump fluid.

Inlet fittings are a variable. The Robinair 15400 has a tee with 1/4 and 1/2 inch flare fittings. The J/B has 1/4 and 3/8 inch flare fittings. These can be readily connected to flexible hose or rigid tubing with flare to tubing adapters or standard brass hardware store plumbing fittings. The other option is the ACME fitting. Adapters for ACME fittings are available but (in my opinion) represent an unnecessary complication. Other brands of pump have similar options i.e. some mix of flare and ACME fittings.

Robinair pump with 1/2” hose adapter. The 1/4” port has a cap and is used as the vent. The exhaust port to the right has been replaced with a hose connector to permit venting to the outside.

McMaster-Carr [4] has very nice stainless flare to tubing adapters. The 3/8” flare to 3/8” tube is part number 5670K25 and the ½” flare to ½” tube is 5670K29. They carry a number of other combinations.

If you get a pump with two inlet ports (pretty much standard except at the very low end), you can use the smaller port as a vent valve by just loosening the supplied o-ring sealed cap.

Pumps with inlet isolation valves are difficult to find in the Chinese pumps. Just beware that the anti-suck back valves in these pumps tend to be pretty ineffective so vent the system immediately after shutting down the pump or include a separate isolation valve.

For hose, it it best to use thick wall vinyl tubing with steel wire reinforcement. These will not collapse under vacuum and won’t kink when going around corners.

***On-Pump Manifold***

For demonstrations and classroom use, integrating a manifold with the pump can be useful and convenient. Below is a picture of the manifold assembly that I had designed.

Except for the brass KF fittings, all of the components are standard hardware store stuff. The connection to the pump is a brass flare to NPT adapter. The KF16 flange to the right is for a gauge. The brass needle valve should be installed with the internal sealing surface toward the pump. The flange at the top is a KF40. Normally, a KF to compression adapter would be used for connecting a glass chamber. This could be replaced with a bell jar base plate or other apparatus. The pipe threads need to be sealed. I use "5-minute" clear epoxy cement.

Since it's now very difficult to find brass vacuum fittings, stainless adapters can be used. These may be found at pretty reasonable prices on eBay.

If more precision is needed for the leak valve, an ARO Ingersoll-Rand needle valve is a fairly economical option. These have a fine adjustment and may be locked in position. You can also use the 1/4" or 3/8" NPT version as an inline throttle/isolation valve.


A photo of the ARO valve (1/8" NPT) is shown to the right.

***References***


1. https://www.labrats.org/
2. https://www.youtube.com/results?search_query=%22Citizen+Scientists%27+Workshop%22+channel
3. http://www.belljar.net/2011_csl_vacuum_overview.pdf
4. https://www.mcmaster.com


**A Simple, Single Supply Thermocouple Gauge**

Mark Atherton

*This article builds significantly on the 741-based controller presented in the Bell Jar Vol. 1, No. 4 (Autumn 1992) with an addendum in Vol. 3, No. 3 (Summer 1994) – Ed.*

I am novice vacuumeer, with a background in electrical engineering and a desire to explore many aspects of this new-found technology from the comfort of my office. One of the obstacles is that the vacuum pump system is located in the garage, and is there because of noise and oil related issues. The bell jar and associated gubbins are portable, detachable from the main vacuum hose by way of a KF25 flange, and isolated by a valve.

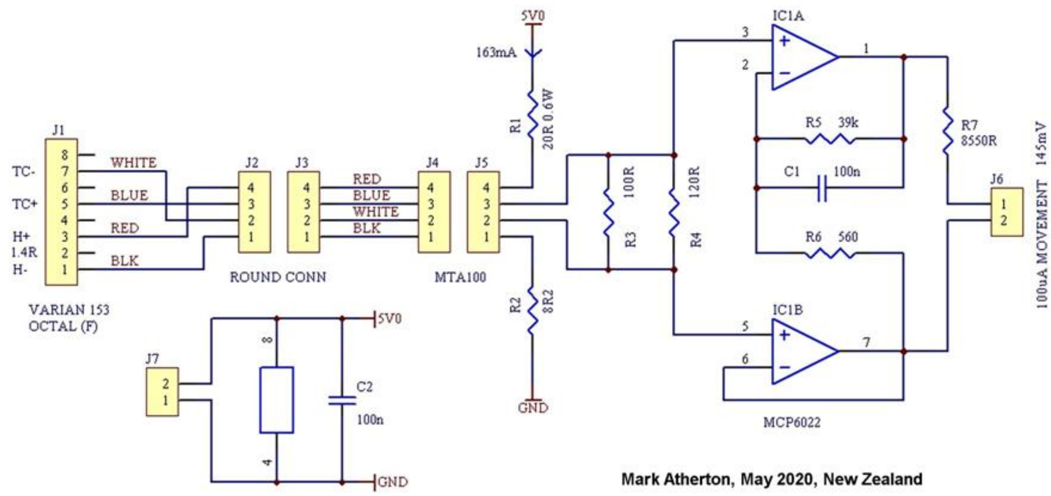
With the bell jar isolated from the pump, some simple means is required to indicate approximate vacuum, as a means of ensuring that any electron-gun (or similar) within the jar is at a safe pressure before being powered up.


A small, integrated unit was envisioned but the need for yet more trailing wires, power supplies, etc. was deemed most undesirable. It was also contemplated that it could be battery powered, which is bordering on prohibitive given the 160+ mA heater current required (more on that later). The lovely old design using the 741 was quite a source of inspiration, but the op-amp requires a split power rail and the heater yet another power source. How much of this could be simplified by using modern technology, and a little thought…

The single most bothersome constraint on the system design is that the heater and thermocouple elements are not isolated. Having said that, with the heater operating around a volt or so elevated from ground by way of a resistor it is unlikely that the thermocouple outputs are likely to be too different than the heater potential. Provided the input common-mode range of a suitable (modern) op-amp exceeds the heater potential range then we may be in business.

A further arbitrary constraint was that it be able to operate off of a single supply in the range 5-10 volts, so usable with USB, or battery power.

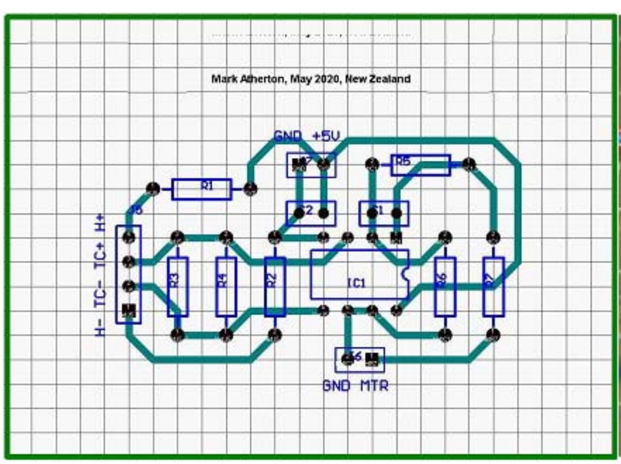
Referring to the schematic on the next page, the input stage of the amplifier is instrumentation-amplifier like, except that the lower buffer is simply a voltage follower, to provide a current sink or source for the reference voltage provided by H-. IC1B, pin 7 is taken as the reference level from the amplifier, and can move up or down, and is mainly controlled by the voltage drop across R2, and set by heater current.

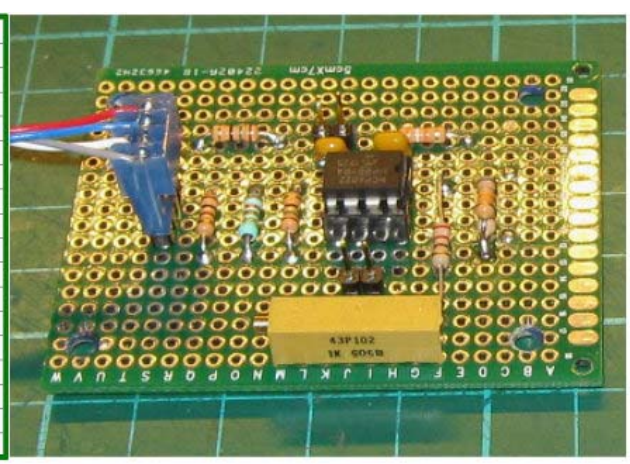



Stage gain is provided in the usual manner by R5/R6, and set to roughly 70. Early experiments indicated that the maximum output from the thermocouple was 10 mV (not 14 as expected), so R6 was replaced by a resistor / trimmer combination. Presumably the TC low output indicates that the unit needs to be degassed, or baked. This may be undertaken when hunnious-bunnious (possibly from the Latin) is out of range of the kitchen.

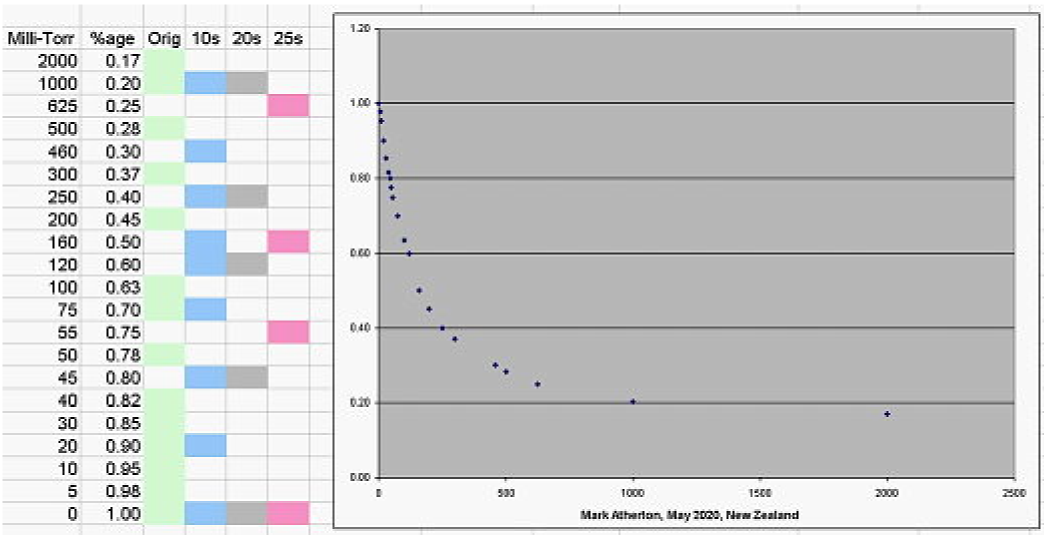
I am not entirely sure why one might want to do so, but given the 0-5V ranges of both outputs from the op-amps, they could be fed into Analogue to Digital converters (in a microprocessor), and subtracted in the digital domain to yield a raw value. This could then be transported over the network for remote monitoring using an Arduino processor and WizNet TCP stack etc. It's all so easy nowadays.

The electrical stuff was initially designed as a single sided printed circuit board, then loaded and wired onto matrix board using thin copper wire instead of copper PCB tracks. The layout is shown below along with a picture of the completed board.



The next issue that needed addressing was indicator type. It didn't take too much thought to realise that having a large analogue display with a minimal number of readout points would provide the most utility; this unit is intended as an indicator, not a calibration reference (!).



| Milli-Torr | %age | Orig | 10s | 20s | 25s |
|---|---|---|---|---|---|
| 2000 | 0.17 | | | | |
| 1000 | 0.20 | | | | |
| 625 | 0.25 | | | | |
| 500 | 0.28 | | | | |
| 460 | 0.30 | | | | |
| 300 | 0.37 | | | | |
| 250 | 0.40 | | | | |
| 200 | 0.45 | | | | |
| 160 | 0.50 | | | | |
| 120 | 0.60 | | | | |
| 100 | 0.63 | | | | |
| 75 | 0.70 | | | | |
| 55 | 0.75 | | | | |
| 50 | 0.78 | | | | |
| 45 | 0.80 | | | | |
| 40 | 0.82 | | | | |
| 30 | 0.85 | | | | |
| 20 | 0.90 | | | | |
| 10 | 0.95 | | | | |
| 5 | 0.98 | | | | |
| 0 | 1.00 | | | | |



Varian presents a calibration table for the 531 TCs, similar to above. However, they only publish the 14 points to the left of the light green blocks, so some form of cunning interpolation was required before the data would be useful for a scale with increments of 10s (10 per range), 20s (5 per range), or 25s (4 per range). As it turned out, having 5 steps (plus atmosphere) gave a good balance between resolution and readability. Rather than attempt a numeric solution to interpolate percentage readings for required values for the ordinal points, a visual solution was attempted. Basically the raw graph was drawn using the manufacturer's data, then points were inserted (ex: 40%), and the associated pressure twiddled with until the resulting graph appeared to follow, as nature intended. While I am not promoting this as a rigorous solution, it is certainly fit-for-purpose in this case.

The next problem was that the indicator should move left as pressure is reduced. Some effort was taken investigating a mechanical as well as an electrical bias to move the indicator to full scale as its starting position then moving back as pressure reduces. I did laugh out loud with the realisation that turning the meter upside-down accomplishes exactly what is required. Several other friends (including my wife) did the same having explained the puzzle, as well as the solution.

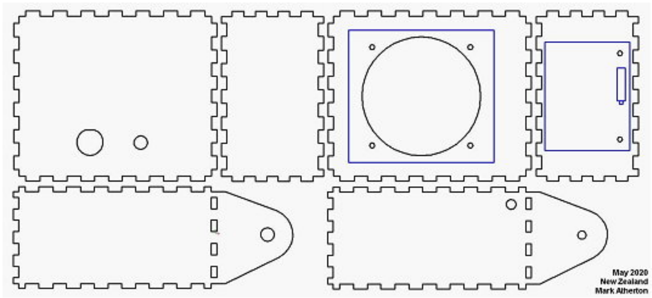
The old scale from the meter was scanned, and suitably edited to add the new ordinal points. A new scale printed and attached to the rear of the old scale.

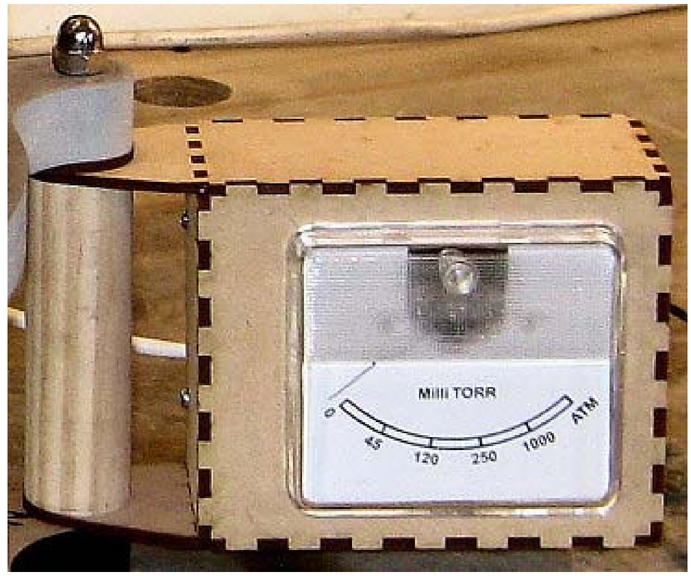
While the linearity (logiarity ?) of this design is fit for purpose, the obvious omission from the existing design is an offset control. The law of the scale seems reasonable, but a tighter fit should be possible with offset, as well as gain trims.


Next was the issue of a suitable enclosure. The good news is that a 70W laser-cutter was to hand; the desire to integrate the gauge as part of the bell jar base turned out to be remarkably simple.

The white cable, to the rear and left of the indicator connects to the thermocouple via an octal valve (tube) socket. The black wire heading off to the right is terminated in a full size USB ‘B’ type plug, then onto a USB power brick plugged into mains power.

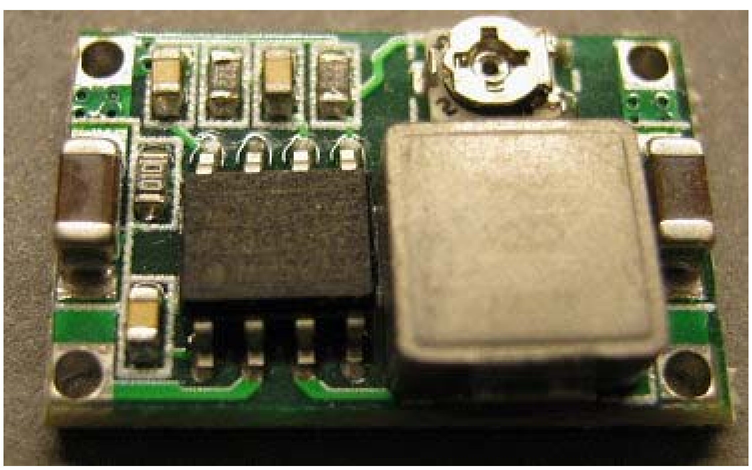
The enclosure cutting drawing started life as a DXF file generated using Inkscape, with the ‘laser cut box’ extension. This DXF was imported by Autosketch, where it was edited to add the various extra features such as the swing arm, and the hole to insert the screwdriver to adjust calibration (an apparently orphan hole in the lower swing arm). This design was cut from 3mm MDF and then glued. The rear panel is of a sufficiently tight fit that it is held in place by friction.




Finally, moving back to the question of making the unit battery powered. The single largest burden for the power supply is heater current, which in the case of the Varian 531 is 163mA. In its raw state, this is no mean feat for all but the most hefty battery packs. I did find some very small switching regulators based on the MP2307 switched mode power supply. These units can operate down to 4.7V on their inputs, and 0.95V on their outputs.

It should be quite a simple task to fetch the 0.95V reference voltage from a 5.6Ω sense resistor in the schematic (was R2). I = V/R, so I = 0.95/5.6 = 169mA. The output from the regulator would be fed into J5, pin 4 (instead of R1), and the switcher would draw power from the (nominally) 5V rail. The circuit described above is a switched mode current source, so will work with a wide range of input voltages (up to 23V), but beware that the MCP-6022 op-amp is only rated up to 5.5V, so you may need to move to a higher voltage amplifier like the LMC-6482 which is good for 12V.



MP2307 based switched-mode power supply

In terms of improvements of power efficiency for all of the bother of adding this current source, let's assume that the output load is about 1.2V (0.95V ref + 0.23V heater @163mA). This is an output power of 196mW. With 80% SMPSU efficiency, assume input power to be 0.25W. Assume that 4 x AA cells are used as the power source (6V), so input current would be in the order of 42mA. Assume that the AA cells are FDK LR6 with a capacity of 2700mAH, this should give battery life in the order of 64 hours, which is quite respectable

Be warned, the above notes about the switched mode current source have not been implement yet, so proceed with caution.

With best wishes, Mark Atherton, New Zealand, 10 May 2020, markaren1@xtra.co.nz



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

April, May and June 2011
***In with the Good Air, Out with the Bad***. This 3-part series covers the components that are used to introduce gases into a process chamber such as mass flow controllers (Part 1), components that are used to control gas flow within the chamber such as throttle valves (Part 2) and issues and techniques that are used to handle process system exhaust gases and other byproducts (Part 3).

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**

The 10 volumes of the printed *Bell Jar* had a high proportion of reader projects. If you are working on something that is vacuum related that may be of interest to others, please contact me.

Next month will have some more on my experiments with atmospheric pressure plasmas. This will focus on the atmospheric pressure plasma jet (APPJ). There will also be a contributed article on refurbishing old vacuum gauges and some related topics.

That's it for this month. Stay healthy!

Steve