Lesker Tech "...vacuum science is our business."

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Pumping By Numbers

In my experience, a vacuum pump is selected on three criteria: (1) Do we have a pump on-site that I can purloin? (2) What is its ultimate pressure? (3) What is its pumping speed? Ignoring larceny, I'll concentrate on last two.

Ultimate Pressure

A pump's *ultimate pressure*, often called its ultimate vacuum, is a value measured when the pump's design is finalized and an example built. In general terms, it is measured by blanking the pump's inlet with a pressure gauge; operating the pump for some time; recording the pressure achieved and calling that the ultimate pressure. Since there are many pressure units, you will see ultimate pressures quoted in torr, millibar, Pascal, inches of mercury, etc.

Sometimes the value is called *ultimate total pressure* (utp) with a reference to a Pneurop or DIN standards number. It means the same thing as ultimate pressure but was measured under the rigors imposed by those standards organizations rather than by the American Vacuum Society. Occasionally, for backing pumps, you will see a weird measure called *ultimate partial pressure* (upp) with a value 10 or 20 times smaller than the ultimate total pressure. What 'upp' means isn't relevant here, but I know folks who assumed it equated to 'utp' and greeted it with ooo's and aah's. Boy, were they disappointed!

Now to the specifics—we have a backing pump with a stated ultimate pressure of 1 x 10^{-2} torr. That means if we hook it to a chamber without leaks, we'll get 1 x 10^{-2} torr in the chamber, right? **Wrong!**

Remember, the pump's ultimate pressure was measured using a brand new pump; with fresh, low vapor pressure oil; with the minimum outgassing surface area; and under ideal ambient conditions. Our 'larceny' probably got us a tired, worn pump; oil that had been cracked by previous use and now has a high vapor pressure; and we mounted it where the ambient approaches 40°C. Indeed, no matter how new the pump and wonderful the conditions, the chamber will have very different characteristics from those used when the pump's ultimate pressure was determined.

To reinforce this point, consider a turbo pump with an ultimate vacuum of 5 x 10^{-11} mbar. If we connect it to a glass bell jar, sealed with an 'L' gasket, we'll get a base pressure of 5 x 10^{-11} mbar, right? **In your dreams!**

So, let's make something clear—the pump's ultimate pressure tells us what the pump can do for itself. When attached to a chamber, the pump's ultimate pressure is no more than a vague pointer to what will happen. The chamber's base pressure depends on Pump Throughput, Gas Load, and the 2nd principle of vacuum technology (see *Lesker Tech* Vol 1 Issue 1, but we'll come back to this many times).

Pumping Speed

This specification is often a real teaser for folks new to vacuum. It is quoted in units of volume per unit time such as: *liters per second* (L/s); *cubic feet per minute* (cfm); *cubic meters per hour* (m^3h^{-1}) and **pressure is never mentioned**. As explained in *Lesker Tech* Vol 1 Issue 1*,* it is a measure of the volume of gas (at any pressure) that is removed from the system in unit time.

But here we will add a few wrinkles. First, pumping speed is measured under the same ideal conditions used to measure ultimate pressure—minimum volume, right at the pump inlet, lowest possible outgassing rate, ideal conditions, etc. Second, pumping speed is specified as a single value. Does this mean the pump has this quoted pumping speed 'at any pressure' from atmosphere to its ultimate pressure? No! Look at the *pumping speed curve* (pumping speed vs pressure) found in the pump manufacturer's literature. The most obvious characteristics are: the pumping speed is roughly constant over a wide pressure range but then droops sharply. For backing pumps, the line droops at the lower pressure end (Fig 1). For high vacuum pumps, it's the higher pressure end (Fig 2). For roots pumps, it's both ends (Fig 3).

Do you care about pumping speed curve drop off? Well, you should for at least two reasons. Let's quantify an example with two pumps: a 3 cfm mechanical pump has a curve showing zero pumping speed at 1 x 10^{-2} torr; a 400 L/sec high vacuum pump showing its inlet pressure should not exceed 1 x 10^{-3} torr.

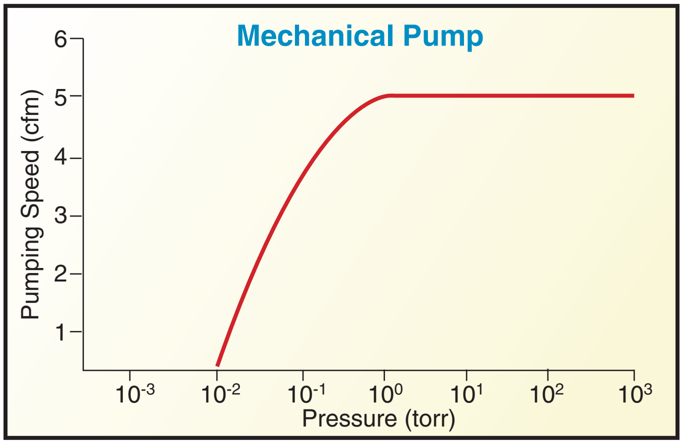

Figure 1

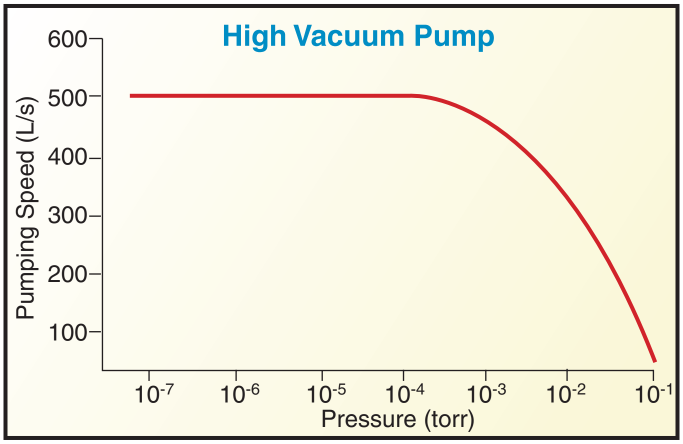

Figure 2

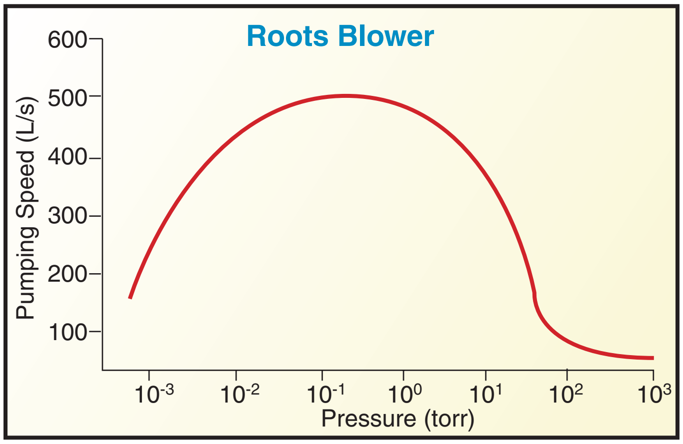

Figure 3

1. What happens if we cross-over from mechanical pump to high vacuum pump? The 'smart' answer is, nothing very good. The lowest chamber pressure using this mechanical pump is clearly much higher than the tolerable inlet pressure for the high vac pump.

2. Let's say we are sputtering. What happens if we want to let in 100 sccm gas flow into the chamber and maintain a pressure of 5 x 10^{-3} torr? First we note neither pump is anxious to be at this pressure....... (*But we'll leave this as this issue's cliff hanger.*)

Pump Throughput

Let's return to the high vac pump's pumping speed curve again, and do some simple arithmetic. Multiply the pumping speed (at some pressure) by that pressure and we get a value for the **pump thoughput.** This is the **quantity** of gas removed from the pump's inlet in unit time and is measured in pressure-volume/time units such as *torr.liter/sec* (T.L/sec), *standard cc per minute* (sccm), *Pascal.cubic meters/sec* (Pa.m^3.s^{-1}).

Pumping Speed L/sec	Pressure torr	Throughput torr L/sec
20	100	2000
20	10	200
20	1	20
20	0.1	2
3	0.01	0.03

Notice, that while the pumping speed is constant, the pump throughput falls linearly with decreasing pressure. But where the curve droops, as in the last entry, pump throughput is the proverbial "lead balloon."

As stated above, this chart represents the quantity of gas (per unit time) the pump removes from its inlet. What does it tell us about the quantity of gas (per same unit of time) the pump removes from the chamber? In a word—**everything**! Remember the second principle in *Lesker Tech* Vol 1 Issue 1,

Gas In = Gas Out

If the pump is removing **q torr.liter/sec** of gas from its inlet, then the chamber's **gas load** must be supplying exactly **q torr.liter/sec** (To be strictly accurate, we must qualify the chamber as "at constant pressure.")

But, and here comes the other shoe, the same **quantity** doesn't mean the same **pressure**. Knowing the pump throughput tells you nothing about the chamber's pressure. For example, if the pump's inlet pressure is 2 x 10^{-6} torr with a pumping speed of 1000 L/sec, the throughput (and the gas load) are 2 x 10^{-3} torr.liter/sec. However, suppose we measure the chamber pressure and it is 1 x 10^{-4} torr. We can calculate the "pumping speed" from the chamber by dividing the gas load (2 x 10^{-3} torr.liter/sec) by the pressure (1 x 10^{-4} torr) and getting the answer 20 L/sec.

"Other shoe-ism" couldn't get more dramatic. Here is a 1000 L/sec pump that has the effect of a 20 L/sec pump on the chamber! Can this really

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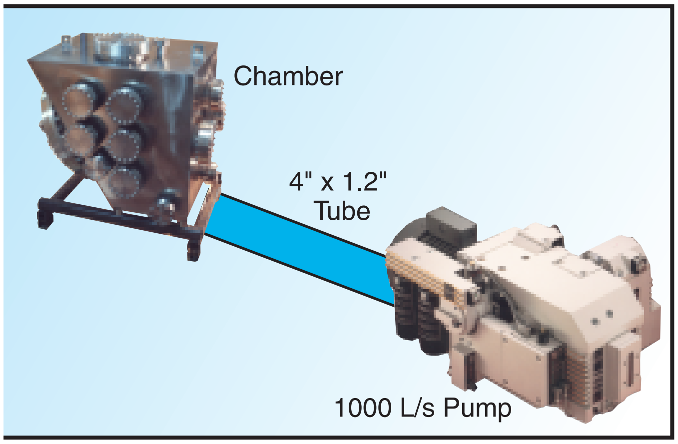
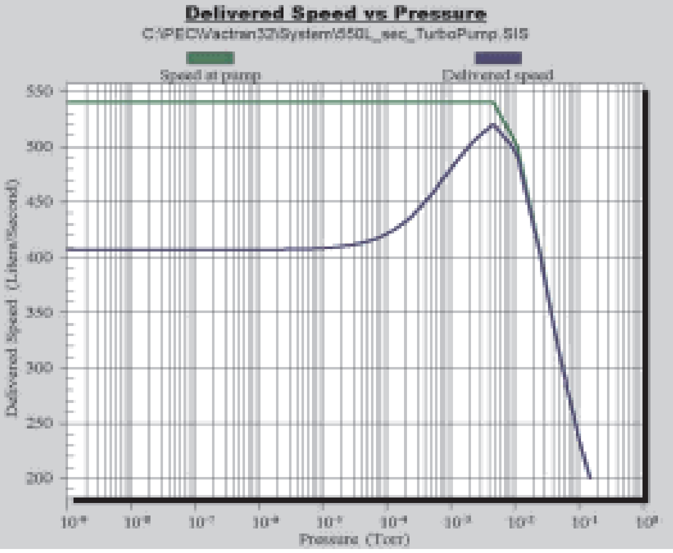
happen? Oh yes! A piece of tube 4" long by 1.2" diameter placed between pump and chamber will create exactly these conditions. Would anyone be daft enough to do that to a 1000 L/sec pump? Hhhmmm! Time for me to diplomatically exit the paragraph without answering.



Effective Pumping Speed

So, here's a nice little nugget. What happens at the pump's inlet is a function of the **pumping speed** (PS). But what happens in the chamber is a function of the **effective pumping speed** (EPS). The 20 L/sec we calculated earlier for putting that tube between chamber and pump was an EPS. Using the VacTran Vacuum Calculations program gives PS and EPS immediately.



How can we relate PS and EPS? Well, we know EPS can **never** be larger than PS. Indeed, since PS is measured under ideal conditions and the pump must always be mounted to the chamber via some sort of flange, EPS **can never equal** PS. The trick is to keep EPS as close as possible to PS and you do that by making pump-chamber connection: **short, straight, and fat**. We will grind this vacuum technology grist many times in future issues.

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