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The Vacuum Venturi – Explained

Vacuum Generator. Vacuum Ejector. Vacuum Venturi. What is the difference between these three? Nothing. They are all the same device. They are air- or fluid-powered, vacuum-generating devices and for the sake of explanation, we shall refer to them as generators. However they are not the same as traditional vacuum pumps. The term "vacuum pump" refers to a mechanical device that utilizes an electric motor or other rotary power unit to drive a mechanical pump assembly. Some manufacturers refer to their air-powered vacuum generators as pumps, and this creates a certain amount of confusion among vacuum users.

In this issue of This Is Vacuum, we shall be reviewing the working principles of compressed air-powered vacuum generators, offering an explanation of how they actually work and the difference between single- and multi-stage versions, their application in industry, their benefits and indeed their shortcomings.

WORKING PRINCIPLE (FIG 1)

The working principle of the vacuum generator can best be described by relating to the effect of a cigarette being smoked by the driver of a vehicle. When the vehicle is moving along the road at speed, high-speed air is passing the vehicle, past the window that is slightly open. This window "orifice" creates the venturi effect and "sucks" the smoke from the cigarette out of the window. In effect, this air passing by the open window is creating a vacuum, be it a slight one, on the inside of the vehicle. Referring to Figure 1, this is what is happening as compressed air (P) passes through the vacuum generator and rapidly passes the orifice between the feeding nozzle and the receiving nozzle or diffuser (1). Directly underneath this orifice is the vacuum port, which is attached to the vacuum system or as shown, a vacuum cup, where air is drawn into the generator at point (V). The combined compressed air (1) and application air (V) exit together through the exhaust of the generator (R).

Consequently, when the vehicle comes to rest or the compressed air is turned off, the venturi effect stops.

The difference between a single-stage venturi and a multi-stage venturi is simply the efficiency of the compressed air used to create the vacuum flow. A single-stage venturi offers a vacuum flow versus compressed air flow ratio of <1:1. However, a multi stage unit can have a ratio in excess of 4:1.

How is this possible? Figure 1 shows a single-stage generator (similar to the moving vehicle principle) and Figure 2 shows a multi-stage generator in operation. Referring to Figure 2, compressed air is connected at the inlet port (P). The first stage of the multi-stage unit (1) "sucks" in air from the application (V). Assume this venturi uses 10SCFM of compressed air. For the sake of calculation and simplicity in understanding the mechanics of this device, this first stage (1) pulls in a further 10 CFM from the application.

Therefore, the second stage (2) has 20 CFM flowing through the nozzle assembly. As the vacuum level increases, the flapper valve opens and the 20 CFM pulls in a further 10 CFM from point (V) and therefore, the third nozzle assembly (3) flows 30 CFM into the fourth stage venturi (4), which now has 40 CFM (P+1st+2nd+3rd) flowing through it and then pulls in another 10 CFM to make a total vacuum flow of 40 CFM generated using the initial 10 CFM of compressed air, which is how the 4:1 ratio is created. Consequently, using this example, the exhaust (R) flows a total of 50CFM to atmosphere.

Of course, depending on the design of the vacuum generator, the above 10 CFM staged event varies, but the principle of operation is the same.

To summarize, a multi-stage ejector creates more vacuum air flow for the compressed air used. That is the single biggest advantage and certainly the main reason why multi-stage generators are used on larger vacuum flow applications.

As a general guide, it takes approximately 1 HP of compressor power to generate 4 CFM of compressed air at 90 PSIG. Therefore, if your vacuum application requires 40 CFM of vacuum flow, a single stage unit will need a minimum of 40 CFM of compressed air, whereas a multi-stage requires only 10 CFM. That's a saving of 30 CFM or about 7.5 HP or 5.6 kW. This is a general conclusion, but the compressed air consumption of single-stage generators is considerably higher than that of multi-stage models.

The flapper valves shown in the multi-stage generator (Figure 2) open when the vacuum level in each stage is high enough to bring the next venturi segment "on line." This is the reason why single-stage ejectors react quicker than multi-stage ejectors and is a definite advantage in certain high speed applications.

COMPARING SINGLE AND MULTI-STAGE GENERATORS

Table 1 shows the comparison between two vacuum generators, one being a single-stage unit and the other being a multi-stage unit from different manufacturers from a real life test where the customer was considering both technologies for a high-speed pick-and-place operation.

The red highlighted cells indicate a longer time for the specific generator to reach the stated vacuum level. As you can see, the single-stage venturi is quicker in the majority of cases.

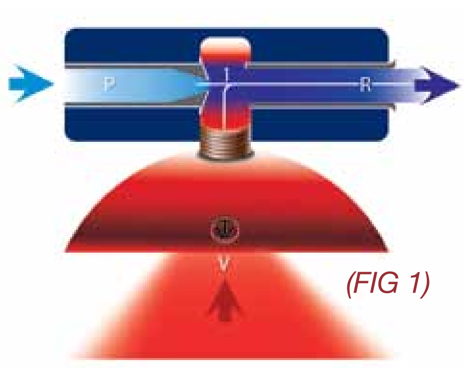
This is because the multi-stage unit has a dwell period between the individual stages coming "on line." The multi-stage venturi uses less compressed air as explained above, but the single-stage venturi takes less time to reach a vacuum level, and therefore, the unit is using more compressed air but for

TABLE 1

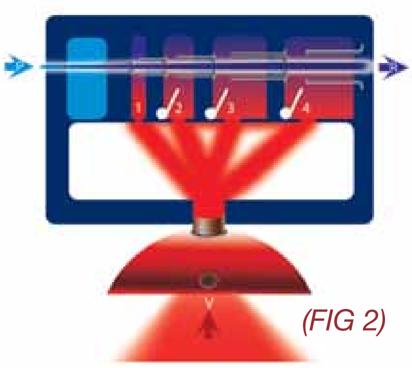
Total Time from 0"Hg		
Vacuum Level	Single Stage	Multi Stage
0	n/a	n/a
3	0.053	0.034
6	0.107	0.087
9	0.165	0.159
12	0.228	0.269
15	0.300	0.430
18	0.387	0.626
21	0.500	0.882
24	0.679	1.308
27	1.187	2.688

Total Time from 3"Hg		
Vacuum Level	Single Stage	Multi Stage
0	n/a	n/a
3	n/a	n/a
6	0.054	0.053
9	0.112	0.124
12	0.175	0.235
15	0.247	0.396
18	0.334	0.592
21	0.448	0.848
24	0.627	1.274
27	1.134	2.654

Total Time from 6"Hg		
Vacuum Level	Single Stage	Multi Stage
0	n/a	n/a
3	n/a	n/a
6	n/a	n/a
9	0.058	0.071
12	0.121	0.182
15	0.193	0.343
18	0.280	0.539
21	0.393	0.795
24	0.572	1.221
27	1.080	2.601



(FIG 1)



(FIG 2)

a shorter time. Consequently, knowing the performance of individual vacuum generators, single or multi-stage, is crucial in the correct selection in an application to maximize efficiency and productivity of the task in hand.

But different manufacturers offer different efficiencies (compressed air used compared to vacuum flow/evacuation time) than each other. What determines how much compressed air a vacuum generator uses? The size of the nozzle orifice(s) in the first stage (the only stage in a single-stage generator). For example, a 1/16" diameter hole will flow 5.1 SCFM @ 90 PSIG. Therefore, if two totally different vacuum generators have the same initial orifice, they will have the same compressed air consumption. It's the design of the venturi nozzle(s), the materials used, the material finish (how smooth the compressed air passage is through the nozzle), the generator cavity design and so on that determines how efficient the generator is. It is very easy to make a vacuum venturi. Getting the maximum vacuum flow from the compressed air used is the hard part.

COMPARING VACUUM GENERATORS TO VACUUM PUMPS

Many manufacturers make vacuum generators and many make vacuum pumps (mechanical rotary vacuum pumps). However, few manufacture both technologies. Therefore, vacuum generator manufacturers and vacuum pump manufacturers typically pitch their technologies against one another in the marketplace in an attempt to convince the user of their advantages over the other. They are both good technologies for creating a vacuum in an industrial application. It's the application itself that determines which technology should be used based on performance required and overall costs.

One of the most important aspects of a vacuum application is the selection of the correct components and this goes far beyond either a vacuum generator or pump. However, the basic differences of vacuum generators and vacuum pumps are highlighted in Table 2.

As you can see from Table 2, the generator offers a longer list of advantages. However, this is not evidence that the generator is a better option. Vacuum pumps are normally used in constant vacuum duty installations, such as central vacuum systems, or machinery that needs a continuous higher vacuum level flow, such as meat packaging or similar applications.

Compressed air is an expensive overhead of any industrial production facility and is often overlooked by the user. Just because they have capacity in their compressed air system does not necessarily mean they should use it. That said, vacuum generators offer a very simple and if applied correctly, an efficient method of creating a vacuum for the machinery or manufacturing process. More often than not, a vacuum generator is simply turned on and off using a compressed air control valve. This method, although simple, is often a very expensive and inefficient method of vacuum creation.

Figure 3 shows the vacuum flow of a typical vacuum generator at different vacuum levels. As you can see, the flow rate decreases considerably as soon as a vacuum is started to be created in the application. Therefore, to stop and start a vacuum generator from atmospheric pressure (no vacuum) every time means that the user will have to wait until a safe vacuum is reached before the production cycle starts. An alternative to this is to keep the vacuum circuit at a higher vacuum level all the time. Referring again to Table 1, the time difference between reaching 15" Hg from 0" Hg compared to reaching 15" Hg from 6" Hg is some 25% quicker. This could be a very considerable time difference in a larger system and should be considered because of this. The way to create this constant system vacuum is to use a vacuum valve to turn the vacuum on and off instead of a compressed air valve to control the supply to the generator. Utilizing different vacuum components, such as a vacuum valve, can offer considerable production throughput increases while at the same time reducing costs in running the vacuum system.

Different methods of vacuum creation and proper utilization of additional vacuum components to maximize efficiency and minimize costs will be discussed in forthcoming issues of This Is Vacuum. As always, the most important consideration in vacuum generator selection, like all production machinery, is the cost of ownership versus productivity of the machine.

For more information, contact Daniel Pascoe at www.vacuforce.com. Vuototecnica USA is a brand of Vacuforce Inc. (Graphic design for this article provided by Shamy Kaul.)

(FIG 3)

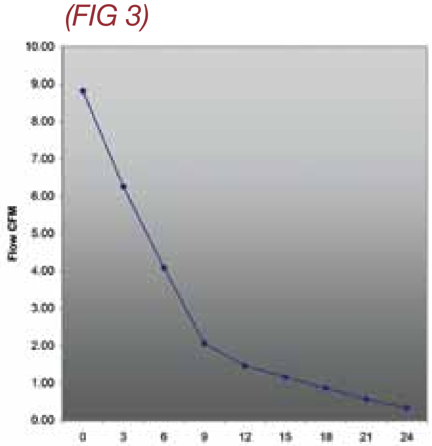


TABLE 2

General Differences Between Vacuum Generators and Pumps	
Vacuum Generator	Vacuum Pump
Less capital cost	More efficient at higher vacuum levels
Smaller in size	Stand alone power unit
Lesser weight	Higher vacuum levels
Vibration free	Higher vacuum flow rates
No heat generated	Ability to handle various media
Easy to cycle on and off	
Many different materials available	
Virtually maintenance free	
Very portable	