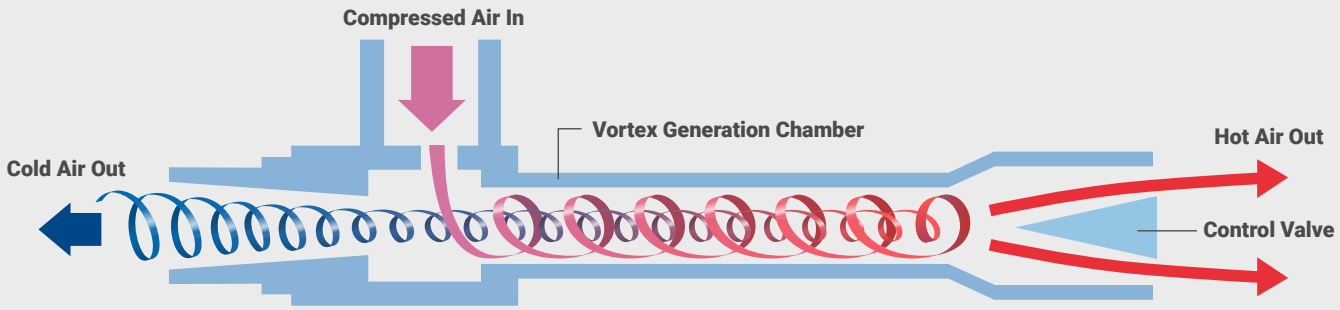
Utilizing Vortex Tube Technology to Create a Cold Air Knife

With the evolution of customer applications often comes needs for new and customized technology. With the cooling ability of vortex tube technology, customers often request that cold air be supplied over a wider area than just the singular output that the vortex tube provides. Over the years, our engineering team has often been asked the question, “Can I use a vortex tube to supply cold air to a Vortec compressed air style air knife?” The short answer is, technically yes, but you may not get the results that you are expecting, and it could be costing you money in the long run.

This question has been asked for years and up until 2003, when ITW Air Management acquired Vortec’s sister company, **Paxton Products**, a leading manufacturer of blower driven air knife systems, the answer was typically **NO**.

There are multiple challenges we are faced with when coupling a vortex tube with a compressed air style air knife. To fully understand these challenges, we will first need to have a basic understanding of how a vortex tube works and the limitation of this unique and fascinating device.

What is Vortex Tube Technology?



A Vortex Tube spins compressed air to produce hot and cold air streams, generating temperatures down to 100° F below inlet temperature.

Fluid (air) that rotates around an axis (like a tornado) is called a vortex. A Vortex Tube creates cold air by forcing compressed air through a generation chamber, which spins the air at a high rate of speed (1,000,000 RPM) into a vortex. The high-speed air heats up as it spins along the inner walls of the vortex generation chamber toward the control valve. A percentage of hot, high speed air is permitted to exit at the valve. The remainder of the (now slower) air stream is forced to counterflow up through the center of the high-speed air stream in a second

vortex. The slower moving air gives up energy in the form of heat and becomes cooled as it spins back through the generation chamber. The chilled air continued back through the generation chamber finally exiting through the opposite end as extremely cold air. Vortex Tubes generate temperatures down to 100 F° below inlet air temperatures. The control valve, located in the hot exhaust end of the tube, can be used to adjust the temperature drop and rise for all Vortex Tubes. (See Cold Fraction chart on the next page).

If you want to learn more about vortex tube technology, visit https://www.vortec.com/vortex-tube-short-course.

To summarize vortex tube technology, we are inputting compressed air into a device that results in creating both hot and cold air streams from the two outputs. These air streams are then used for either cooling or heating depending on the application.

If we read further into how the vortex tube works, we will learn that the way this device creates cold air specifically is directly related to the absolute pressure ratio between the inlet air and the cold outlet. Below is a performance table that will give you the various temperature drops and rises based on cold fraction and inlet pressure. **Please note that this table is assuming that the cold and hot air outlets are at atmospheric pressure.**

The table below shows approximate temperature drop and rise achieved by vortex tubes when adjusted to various cold fractions. Cold Fraction is the percentage of cold air produced versus total filtered compressed air consumed by any Vortex Tube.

- Numbers on White Bar = Temperature Drop
- Numbers on Blue Bar = Temperature Rise

COLD FRACTION	10		20		30		40		50		60		70		80		90	
PSIG/BAR	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C
20 / 1.4	63	35	62	34	60	33	56	31	51	28	44	24	36	20	28	15	17	9
	7	4	15	8	25	14	36	20	50	28	64	36	83	46	107	59	148	82
40 / 2.8	91	51	88	49	85	47	80	44	73	41	63	35	52	28	38	21	29	14
	9	5	21	11	35	19	52	29	71	39	92	51	117	65	147	82	220	122
60 / 4.1	107	59	104	58	100	56	93	52	84	47	73	41	60	33	45	25	29	16
	10	6	24	13	40	22	59	33	80	44	104	58	132	73	168	93	236	131
80 / 5.5	119	66	115	64	110	61	102	57	92	51	80	44	66	36	49	27	31	17
	11	7	25	14	43	24	63	35	86	48	113	63	143	79	181	101	249	138
100 / 6.9	127	71	123	68	118	66	110	61	99	55	86	48	71	39	53	29	33	18
	12	8	26	14	45	25	67	37	91	51	119	66	151	84	192	107	252	140
120 / 8.3	133	74	129	72	124	69	119	64	104	58	91	50	74	41	55	31	34	19
	13	8	27	14	46	26	69	38	84	52	123	68	156	87	195	108	257	142
140 / 9.7	139	78	135	75	129	72	127	67	109	61	94	52	76	42	57	32	35	20
	14	8	28	16	47	27	71	39	96	53	124	69	157	88	196	109	259	144

Table Baseline

- Compressed air temperature: 70°F / 21°C
- Pressure Dew Point: -25°F / -32°C
- Compressed Air Pressure: 100 psig (6.9 bar)
- Backpressure: Temperature drops and rises in the chart are based on zero (0) backpressure on the hot and cold outlets of the vortex tube.
- Backpressure exceeding 5 psig (0.3 bar) will reduce the performance of the vortex tube.

Let's work through an example of this:

Let's say that you need to cool a small sensor down to 5°F. You have 100 PSIG compressed air available; the temperature of the compressed air is 70°F and it is dried to -25°F pressure dew point. The delta T from 70°F (Inlet air temp) – 5°F (desired output temp) is 65°F. In the table above, you would refer to the 100 PSIG row and locate the column that has 65°F or higher temperature drop. The chart tells us that with a 70% cold fraction we can expect a 71°F temperature drop or at 80% cold fraction we can expect a 53°F temperature drop. Therefore, we would adjust the hot end valve to provide between 70% and 80% cold end flow and we should be close to the 5°F temperature that we are looking for.

With this knowledge on Vortex Tubes, we now need to understand how the compressed air knife operates and what the benefits of combining a vortex tube with an air knife would be.

What are compressed air knives?

Compressed air knives, sometimes referred to as “curtain transvectors”, are devices that utilize a small amount of compressed air flow to provide a high-volume sheet of entrained air. Air knives are suitable for cooling or drying moving parts or webs of material such as paper, plastic films and thin metal sheets. Vortec offers these air knives in 6, 12, 18 and 24 inch lengths. These air knives consume 5.5 SCFM per inch at 100 PSIG and deliver about 25 times as much flow through ambient air entrainment. For example, a 12” compressed air knife that is being operated at 100 PSIG will consume approximately 66 SCFM and produce an output flow of approximately 1650 SCFM.

Vortec compressed air knives use the impulse principle of air flow amplification. Compressed air is released at sonic velocity through a linear slot which is 0.002” wide. As the sonic velocity air exits the slot, it collides with nearly still air, inducing and entraining a much larger flow. Since the air exits a linear slot, the induced and entrained air forms a powerful sheet or curtain of air.

Why can’t we connect a compressed air knife to a vortex tube?

There are a few reasons we cannot simply connect a compressed air knife to a vortex tube to produce a cold air knife.

1. **Inadequate pressure supplied to the air knife:**

   As we learned earlier, the cold air created by the vortex tube is directly related to the absolute pressure ratio between the inlet air and the cold outlet. We will need to supply enough air to the air knife to make it function properly and to get maximum flow/amplification. By placing an air knife on a vortex tube and supplying the air knife with air from the cold outlet of the vortex tube we will need it to be at a pressure of approximately 50-100 PSIG to take full advantage of its design. This means the back pressure being applied to the cold end of the vortex tube would have to be at that same pressure effectively lowering the pressure drop ratio of the vortex tube and drastically decreasing its performance. In other words, the outlet of a vortex tube is at atmospheric pressure, but a Vortec air knife requires a high pressure at the inlet, so the two are incompatible.

2. **Ambient air will be mixed with the cold air output:**

   Vortec air knives can produce an amplification ration of up to 25 times when compared to the amount of compressed air being supplied to the air knife. That means that for every 1 CFM of cold air that is being supplied by the vortex tube through ambient air entrainment it picks up an additional 24 CFM of ambient air. Compare this to putting a single ice cube into a bucket of water. There may be some temperature change, but it won’t be much as the ambient air will be diluting the cold air.

3. **Thermal conductivity of the air knife will affect the cold air temperature:**

   The compressed air knives are made of aluminum which has a moderately high level of thermal conductivity. Thermal conductivity can be defined as the rate at which heat is transferred by conduction through a unit cross-section area of a material when a temperature gradient exits perpendicular to the area. This means that the compressed air knife is also going to do a pretty good job of transferring the heat in the surrounding ambient air to the cold air being produced by the vortex tube further deteriorating its performance.

Paxton Products Air Knives Offer a Solution

In late 2003, ITW Air Management purchased Paxton Products located in Camarillo, CA. Paxton designs and manufactures high speed centrifugal blowers that are used to supply air to a wide range of air knives and other air delivery devices.

Paxton Air Knives and Air Knife Drying Systems are designed to give maximum efficiency for high velocity air drying and blow off applications. These systems feature a continuous, uninterrupted air slot design that give uniform air coverage over the project area with a standard gap setting of 0.055 inches.

Air knives are used to blow liquids or debris off a wide variety of materials:

- Water and chemicals can be sheared from surfaces after washing
- Bottling and canning facilities use air knives to dry products prior to date coding or labeling
- Fruit and other food products are dried, and dirt and debris are blown off with air
- After cutting or machining, debris and scrap are effectively removed from metal, wood, cardboard, plastic and other surfaces
- Packaged foods are air dried without adding excessive heat
- After applying coatings to parts, foods, etc, excess coating can be sheared off to evenly distribute the coating

When compared to the Vortec air knives the Paxton air knives are:

1. Low pressure, high flow and as a result will not create as much back pressure on the vortex tube allowing for better performance.
2. Designed to provide a laminar sheet of air and since they are designed to operate at much lower pressures the amplification ratio of these air knives will be lower allowing us to deliver colder air that with the compressed air knife.
3. The Paxton Air Knives are made of 304SS which has a lower thermal conductivity than the compressed air knives that are made of aluminum making them a good choice for delivering the refrigerated air from the vortex tube.

With this information, it appears that Paxton Air Knives have eliminated the 3 main issues associated with the Vortec compressed air knife, but is it as simple as combining the vortex tube technology with the Paxton air knife technology?

Real World Application Test

Let's look at a recent application that involved cooling an automotive part. The overall goal was to cool the part from 425°F to 45°F without the use of water/evaporative cooling. The part was made of 6061-T6 aluminum and weighed approximately 1lb.

We ran two tests.

1) Compressed Air Knife

- A Vortec 921-12 - 12" long compressed air knife

VORTEC 921-12 COMPRESSED AIR KNIFE	
Pressure (PSIG)	100
Flow (SCFM)	34
Ambient Air Temp (°F)	73
Beginning Temp (°F)	425
Time to 100°F (min:sec)	1:06
Temp Plateau (°F)	87
Time to Plateau (min:sec)	1:30
Sound @ 1 foot (dbA)	101
Distance from outlet (inches)	3

2) Paxton Air Knife with a Vortex Tube

- For this test our engineering team selected a 12” long Paxton stainless steel air knife with a gap of 0.055”. This length and gap was chosen because it best fit the size of the part that they were cooling, and it closely matched the output of the 328-100-H vortex tube.

PAXTON AIR KNIFE WITH 328-100-H VORTEX TUBE	
Pressure (PSIG)	100
Flow (SCFM)	100
Ambient Air Temp (°F)	73
Beginning Temp (°F)	425
Time to 100°F (min:sec)	1:48
Temp Plateau (°F)	43.5
Time to Plateau (min:sec)	6:00
Sound @ 1 foot (dbA)	114
Distance from outlet (inches)	3

Conclusion

The tests show that the best way to cool components that exceed temperatures of 200°F is to use the Vortec compressed air knife to harness the additional airflow created by the entrainment of ambient air. However, when cooling below ambient temperatures is necessary, it would be necessary to transition from the Vortec air knife to a Paxton air knife that is powered by the appropriate vortex tube.

Therefore, it is wholly possible to create a cold air knife by connecting a Vortex Tube to an air knife. The selection of which solution would best fit your application would depend on certain factors of your unique situation. The engineering team at ITW Air Management are experts on both Vortec and Paxton Products lines. To work through your unique application, feel free to contact techsupport@vortec.com.

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