Equipment used to generate vacuum, as noted earlier, is similar to air compressors. It's even possible to generate compressed air or vacuum with the same machine, depending on how it is installed. Vacuum pumps generally can be considered as compressors in which the discharge, rather than the intake, is at atmospheric pressure.

Recall that the essence of air compression is the increased number of molecular impacts per second. Conversely, the essence of vacuum generation is the reduction of these impacts. The vacuum in a chamber is created by physically removing air molecules and exhausting them from the system.

Removing air from the enclosed system progressively decreases air density within the confined space, thus causing the absolute pressure of the remaining gas to drop. A vacuum is created.

Because the absolute maximum pressure difference that can be produced is equal to atmospheric pressure (nominally 29.92 in. Hg at sea level), it is important to know this value at the work site.

For example, a pump with a maximum vacuum capability of 24 in. Hg cannot generate a 24-in. vacuum when the atmospheric pressure is 22 in. Hg (as in Mexico City, for instance). The proportion of the air evacuated will be the same, however. This pump therefore will pull 22 x 24/29.92 or 22 x 24/30 = 17.6 in. Hg vacuum in Mexico City.

Vacuum Pumps: Basic Operation

A vacuum pump converts the mechanical input energy of a rotating shaft into pneumatic energy by evacuating the air contained within a system. The internal pressure level thus becomes lower than that of the outside atmosphere. The amount of energy produced depends on the volume evacuated and the pressure difference produced.

Mechanical vacuum pumps use the same pumping mechanism as air compressors, except that the unit is installed so that air is drawn from a closed volume and exhausted to the atmosphere. A major difference between a vacuum pump and other types of pumps is that the pressure driving the air into the pump is below atmospheric and becomes vanishingly small at higher vacuum levels. Other differences between air compressors and vacuum pumps are:

- The maximum pressure difference produced by pump action can never be higher than 29.92 in. Hg (14.7 psi), since this represents a perfect vacuum.
- The mass of air drawn into the pump on each suction stroke, and hence the absolute pressure change, decreases as the vacuum level increases.

- At high vacuum levels, there is significantly less air passing through the pump. Therefore, virtually all the heat generated by pump operation will have to be absorbed and dissipated by the pump structure itself.

Vacuum Stages

As in compression, the vacuum-generating process can be accomplished in just one pass through a pumping chamber. Or several stages may be required to obtain the desired vacuum.

The mechanical arrangements are also similar to those for air compression. The discharge port of the first stage feeds the intake port of the second stage. This reduces the pressure, and hence the density, of air trapped in the clearance volume of the first stage. The net effect is, using a Gast diaphragm pump as an example, that the second stage boosts the vacuum capability from 24 to 29 in. Hg.

Oil-Less vs. Oil-Lubricated Vacuum Pumps

As with compressors, the application normally dictates whether an oil-less or oil-lubricated vacuum pump should be used. Either type may be used in many applications.

Oil-Less - Oil-less pumps are almost essential when production processes cannot tolerate any oil vapor carry over into the exhaust air. They also can be justified on the basis of avoiding the cost and time of regularly refilling the oil reservoirs. This is particularly important when the pumps are to be mounted in inaccessible locations.

Modern piston pumps have rings of filled Teflon, which provide hundreds of hours of duty, depending on ambient temperature and air cleanliness. Diaphragm and rocking piston pumps are designed to be oil-less.

Oil-Lubricated - The oil-lubricated types have distinct advantages if proper maintenance is provided. They can usually provide about 20 percent higher vacuums because the lubricant acts as a sealant between moving parts. And they usually last about 50 percent longer than oil-less units in normal service because of their cooler operation. They also are less subject to corrosion from condensed water vapor.

Positive Displacement Vacuum Pumps

Vacuum pumps fall into the same categories as air compressors do. That is, they are either positive displacement or nonpositive displacement machines. A positive displacement pump draws a relatively constant volume of air despite variations in the vacuum levels.

As with air compressors, the principle types of positive displacement vacuum pumps are the piston, diaphragm, rocking piston, rotary vane, lobed rotor, and rotary screw designs. The basic mechanics of each are described in Section 11. The remarks below cover aspects that apply to vacuum applications.

Reciprocating Piston Pumps -The primary advantage of the piston design is that it can generate relatively high vacuums from 27 to 28.5 in. Hg-and do so continuously under all kinds of operating conditions. The major disadvantages are somewhat limited capacities and high noise levels, accompanied by vibrations that may be transmitted to the base structure. In general, the reciprocating piston design is best suited to pulling relatively small volumes of air through a high vacuum range.

Diaphragm Pumps -The diaphragm unit creates vacuum by flexing of a diaphragm inside a closed chamber. Small diaphragm pumps are built in both one- and two-stage versions. The single stage design provides vacuums up to 24 in. Hg, while the two stage unit is rated for 29 in. Hg.

Rocking Piston Pumps -This design combines the light weight and compact size of the diaphragm unit with the vacuum capabilities of reciprocating piston units. Vacuums to 27.5 in. Hg are available with a single stage; two-stage units can provide vacuums to 29 in. Hg. Air flows, however, are limited, with the largest model available today (a twin-cylinder model) offering only 2.7 cfm.

Rotary Vane Pumps -Most rotary vane pumps have lower vacuum ratings than can be obtained with the piston design: only 20 to 28 in. Hg maximum. But there are exceptions. Some two stage oil-lubricated designs have vacuum capabilities up to 29.5 in. Hg. (Also see the section on medium-vacuum pumps.)

The rotary vane design offers significant advantages: compactness; larger flow capacities for a given size; lower cost (about 50 percent less for a given displacement and vacuum level); lower starting and running torques; and quiet, smooth, vibration free, continuous air evacuation without a receiver tank.

Rotary Screw and Lobed Rotor Pumps - Vacuum capabilities of rotary screw pumps are similar to those of piston pumps, but evacuation is nearly pulse-free. Lobed rotor vacuum pumps, like the corresponding compressors, bridge the gap between positive and nonpositive displacement units. Air flow is high but vacuum capabilities are limited to about 15 in. Hg. Capabilities can be improved with staging.

Nonpositive Displacement Vacuum Pumps

Like the corresponding compressors, nonpositive displacement vacuum pumps use changes in kinetic energy to remove air from a system. The most significant advantage of this design is its ability to provide very-high-volume flow rates-much higher than possible with any of the positive displacement designs. But because of their inherent leakage, these machines are not practical for applications requiring higher vacuum levels and low flow rates.

The principle types of nonpositive displacement vacuum pumps are the centrifugal, axial-flow, and regenerative designs. Single-stage regenerative blowers can provide vacuums up to 7 in. Hg with flows to several hundred cfm. Vacuum capabilities of the other designs are lower unless they are multistaged.

Evaluating Vacuum Pump Performance

This section covers important vacuum pump performance characteristics used in evaluating particular types and sizes. Actual pump selection, covered in a separate section, will be based on how these characteristics relate to the intended application.

The primary performance criteria cover just three characteristics:

- Vacuum level that can be produced.
- Rate of air removal.
- Power required.

Somewhat less critical are temperature effects and certain other characteristics.

In general, the best pump for a specific job is the one having the greatest pumping capacity at the required vacuum level and operating within an acceptable horsepower range.

Vacuum Level - A pump's vacuum rating is the maximum vacuum level for which it is recommended. The rating is expressed in in. Hg and is specified for either continuous or intermittent duty cycles.

Most vacuum pumps can't come near the theoretical maximum vacuum (29.92 in. Hg at sea level) because of internal leakage. For a reciprocating piston pump, for example, the upper vacuum limit may be 28 or 28.5 in. Hg, or roughly 93 to 95 percent of the maximum theoretical value.

Internal leakage and clearance volume establish the highest vacuum a pump can produce. For some pumps, this is also the vacuum rating.

In other types, however, heat dissipation is a problem. For these, the maximum vacuum rating might be based on allowable temperature rise. For example, good wear life for some rotary vane pumps requires a maximum 180^0F (82^0C) rise in casing temperature at the exhaust port. Vacuum ratings will be based on this temperature rise. They probably will be higher for intermittent than for continuous duty.

The vacuum rating listed for a pump is based on operation at 29.92 in. Hg. Operating where atmospheric pressure is lower will reduce the vacuum the pump can produce. An adjusted vacuum rating for such locations can be determined by multiplying actual atmospheric pressure by the ratio of the nominal vacuum rating to standard atmospheric pressure:

$$\text{Adjusted Vacuum Rating} = \text{Actual Atmospheric Pressure} \times \frac{\text{Nominal Vacuum Rating}}{\text{Standard Atmospheric Pressure}}$$

Air Removal Rate -Basically, vacuum pumps are rated according to their open capacity, which is the volume of air (expressed in cfm) exhausted when there is no vacuum or pressure load on the pump.

Effectiveness of the vacuum pump in removing air from the closed system is given by its volumetric efficiency, a measure of how close the pump comes to delivering its calculated volume of air. Volumetric efficiency for a positive displacement pump is given by the general equation on page 62. With vacuum pumps, this equation is applied in two different ways:

- **True (or Intake) Volumetric Efficiency** -The volume of air removed during a given time period is converted to an equivalent volume at the temperature and absolute pressure existing at the intake.
- **Atmospheric Volumetric Efficiency** -The volume of air removed by the pump is converted to an equivalent volume at standard conditions (14.7 psi and 68^0 F).

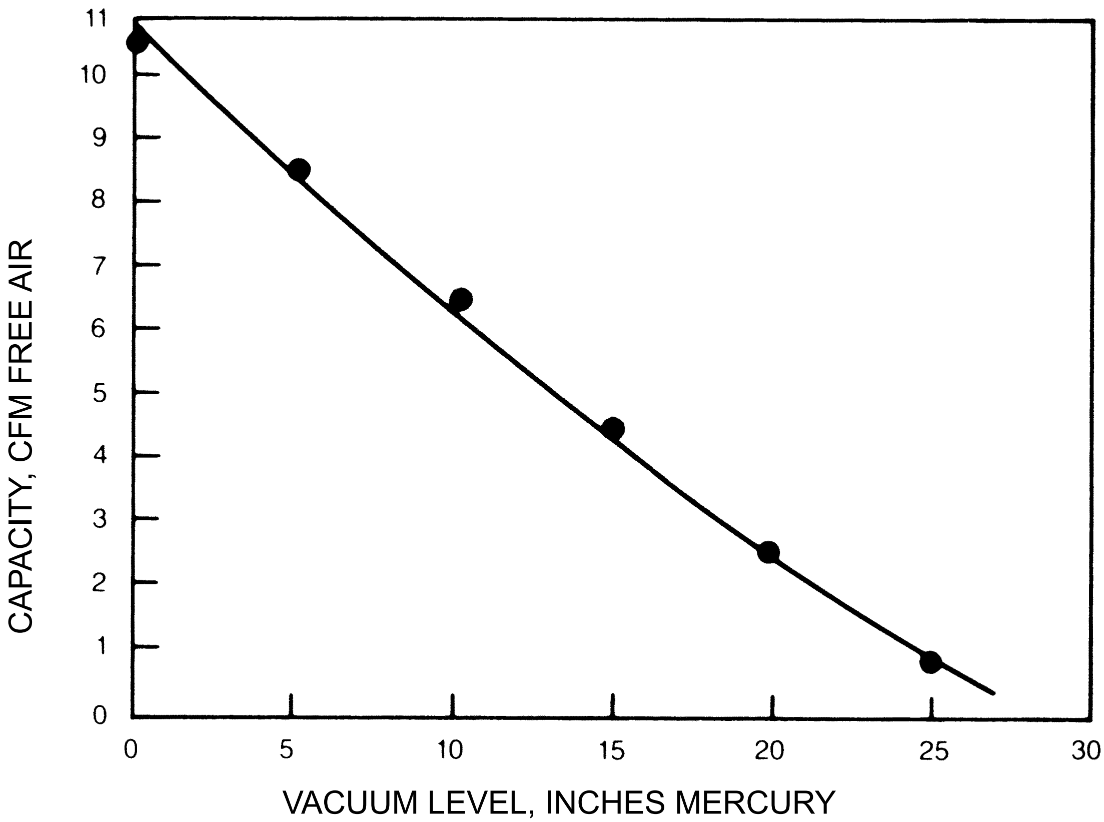
In either case, the displacement is the total volume swept by the repetitive movement of the pumping element during the same time period (usually one revolution). With various vacuum pumps having the same displacement, it is the difference in volumetric efficiencies that accounts for the difference in free air capacities. Since these differences exist, pump selection should be based on actual free air capacity rather than on displacement.

In short, the air removal rate is a measure of vacuum pump capacity. And the capacity of standard machines must be determined from the manufacturers' tables or curves showing cfm of free air delivered at rated speed for vacuum levels ranging from 0 in. Hg (open capacity) to the maximum vacuum rating. Free air capacity at different speeds for a given vacuum also may be included in the manufacturers' performance curves.

As shown in Fig. 44 and 45, the rated capacity of any pump is highest at 0 in. Hg and will drop rapidly as the vacuum level increases. This reflects a drop in both volumetric efficiency and the volume of air that can be drawn into the pumping chamber.

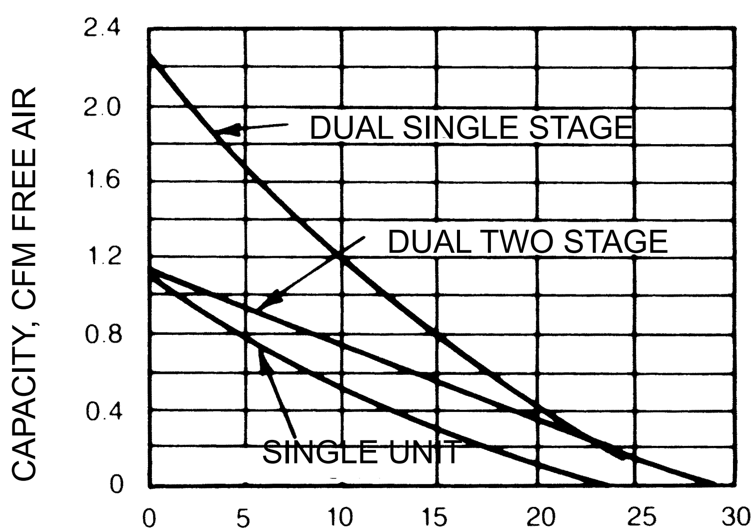
To repeat, a basic characteristic of positive displacement pumps is that capacity drops as the vacuum level increases. Fig. 44 shows this very clearly for a piston pump. The same principle holds for diaphragm pumps.

Figure 44



Capacity vs. vacuum level for a single-stage reciprocating piston pump.

Figure 45



Capacity vs. vacuum level for different types of diaphragm vacuum pumps: single cylinder, twin cylinders in parallel (dual single-stage), and twin cylinders in series (dual two-stage).

In Fig. 45, the single unit designation represents a single-chamber, single-stage pump. The dual single-stage unit has twin chambers operating in parallel. In the dual two-stage unit, the twin chambers operate in series.

Recall that the staging process produces higher vacuum levels because the first stage exhausts into a second stage already at negative pressure. This causes a reduction in absolute pressure of the air trapped in the clearance volume (the space between piston and cylinder head at the time of full compression). But as Fig. 45 shows, the basic capacity of the dual two-stage machine is reduced by 50 percent compared with the dual single-stage pump of the same size.

Fluid Power Horsepower - Different techniques have been developed to evaluate the efficiency of energy use by a vacuum pump. Most vacuum pump manufacturers catalog their test results, including brake horsepower (actual hp) and cfm vs. vacuum level. Fairly accurate evaluations of power needs can be made from such information sources.

For example, the relative efficiency of different pumps can be obtained by calculating the cfm of free air removed per horsepower. Or input horsepower can be compared to the "fluid power horsepower" delivered, which is proportional to the product of gauge vacuum and air flow rate. All comparisons must be made at the same specific vacuum level, usually at 20 in. Hg or above.

Drive Power Requirements -The drive unit must be able to meet the pump's peak power requirement. In other words, it must be powerful enough to assure satisfactory operation under all rated operating conditions. This includes providing adequate energy to overcome friction and inertia effects at startup.

The power requirements of a vacuum pump are relatively low, compared with those of an air compressor. The primary reason is the low compression work requirement. Both the volume flow rate and the pressure difference across the machine are much lower than in a compressor.

When the pump operates near atmospheric pressure, for example, the mass flow rate (cfm free air pumped) is at its highest, but pressure differences between inlet and outlet are very small. The amount of work that must be added per pound of air is therefore very low.

At higher vacuum levels, the amount of work that must be done increases because of the larger difference between inlet and discharge pressure. The mass flow rate or cfm free air pumped drops progressively, however. The total amount of compression work thus remains very low.

Drive Speeds -in addition to actual brake horsepower required for various vacuum levels, catalogs will generally show the speed required to develop various rated capacities.

Effects of Temperature Rise

Vacuum pump performance can be significantly affected by heating of the pump itself. At higher vacuum levels, there is very little air flow through the pump. Most of the air has been exhausted. There is thus very little transfer of internal heat to this remaining air.

Much of the heat generated by friction must be absorbed and dissipated by the pump. Since some pumps generate heat faster than it can be dissipated, a gradual rise in pump temperature results, drastically reducing service life.

One solution is to give careful consideration to pump ratings. For example, a continuous-duty pump should have a high maximum vacuum rating. On the other hand, an intermittent-duty pump may be specified for high vacuum levels if the off period is adequate for effective cool-down of the pump. Complications may arise if the maximum on period greatly exceeds the off cooling period.

Whenever possible, vacuum pumps should be operated with load/unload cycling rather than on/off cycling. When a pump is unloaded, the atmospheric-pressure air being drawn through it carries the accumulated heat away rapidly. When a pump is shut off with vacuum inside, however, heat loss is much slower because it occurs only through the outside of the casing.

Vacuum Pump Selection

The previous section describes how the designer evaluates performance based on vacuum level, air flow, power requirements and temperature effects. This section covers the factors involved in applying the basic characteristics to particular operation and application needs. In short, we wish to narrow down the selection process to a single type, size, and horsepower for the vacuum pump and related system components.

Vacuum Level Factors

Basically, the selection of the appropriate type of vacuum pump is determined by comparing the application's requirements with the maximum ratings of available commercial pumps (Table 7).

But how are required working vacuum levels determined? When a mechanical force is required, the necessary working vacuum is determined in a way similar to establishing pressure requirements of air-operated devices.

Increasing the size of the device to increase its area reduces the working vacuum required. The requirements of specific vacuum devices in the line can be determined by calculations based on handbook formulas, theoretical data, catalog data, or performance curves and tests made with prototype systems.

The primary restriction on the type of vacuum pump that can be used in a given application is the actual system vacuum level determined by the designer. When this level is relatively low (about 15 in. Hg), the designer has a large variety of different types and models of pumps from which to choose. But as vacuum levels rise, the designer has fewer and fewer options, sometimes to a choice of one.

Maximum Vacuum Rating -There are practical limits on the degree of vacuum that can be economically produced to accomplish work. These limits represent the maximum vacuum capabilities of the mechanical pumps used to remove air from the system.

Depending on the type of pump involved, this limit ranges from 20 to 29.0 in. Hg. Very sophisticated and costly equipment is required to obtain higher vacuum levels.

Representative of available commercial vacuum pumps, Table 7 summarizes the Gast line. The Diaphragm and rocking piston types provide the highest vacuum ratings. Also, they are generally preferred for continuous-service applications. Capabilities of oil-lubricated rotary vane pumps, however, approach these levels.

System Control Factors

If the system's vacuum level is controlled by a relief valve, the maximum vacuum required should be selected on the basis of the highest working level of any single air device in the system. But if the system vacuum is controlled by automatic on/off or load/unload cycling of the vacuum pump, the maximum vacuum required is equal to the cutoff value of the control.

Temperature Factors

Temperature is an important consideration from two standpoints:

Environmental Temperature -For ambient temperatures above 100^{o} F (38^{o} C), select a pump rated for higher vacuum operation and provide some external cooling.

Internal Pump Temperature -Ope ration at higher vacuums increases pump temperature and can be the most severe limiting factor on pump operation. Heavy-duty pumps with cooling can operate continuously. But light-duty pumps can operate at maximum vacuums for only short periods; they must be allowed to cool between cycles.

Miscellaneous Type Selection Factors

After the basic step in matching vacuum level requirements with the maximum vacuum ratings of available pumps, the selection process proceeds by determining if any of several factors may influence the decision.

Need for Uncontaminated Air -This can apply to the intake portion of the system, where grit could enter and harm the pump mechanism. More often it applies to the exhaust portion of a system, for example, in a food processing plant where dirty air or oil vapors can contaminate products or materials. The most straightforward solution is the selection of an oil-less vacuum pump.

Maintenance-Free Operation -Nothing mechanical is absolutely "maintenance-free." But if we restrict the term to lubrication, then an oil-less vacuum pump can best satisfy this need, since periodic oiling is not required.

Pulse-Free Air Flow -Rotary vane and nonpositive displacement machines have smooth, continuous air removal characteristics without the extra cost and space requirements of a receiver tank.

Minimum Vibration/Noise -Rotary vane pumps have lower noise and vibration levels than reciprocating machines. The regenerative blower is also basically vibration-free, but the impellers may generate high-pitched noise.

Space Limitations -Again, the rotary vane design is often selected because of its relative compactness. If higher vacuums are required, the rocking piston could be suitable.

Vacuum Capacity Factors

The optimum pump size for an application is determined by comparing the rate at which air must be removed from the system with the capacities of various commercial pumps available (Table 8). In general, small capacity and large capacity pumps that have the same maximum vacuum capabilities will pull the same vacuum on a closed system. The small pump will simply require more time to reach maximum vacuum.

To directly compare vacuum pump and compressor rating data, the air removal rate is calculated in cubic feet of free air per minute (just as in pressure systems). To determine the free air that must be removed, the volume is multiplied by the vacuum level in atmospheres. The latter is obtained by dividing the gauge vacuum (in in. Hg) by standard atmospheric pressure (29.92 in. Hg). Therefore, the formula for free air is:

$$\text{Free Air} = \text{System volume} \times \frac{\text{Gauge pressure}}{29.92}$$

As with compressors, it is necessary to first calculate the free air removal for each work device over a full work cycle. This value is multiplied by the number of work cycles per minute, and the requirements for all the work devices are totaled.

Open Capacity Rating -The above total is then matched with the capacity ratings of available equipment. Generally, to accommodate possible leaks, the selected vacuum pump should have a capacity rating 10 to 25 percent above the air removal rate actually required.

The capacity of a vacuum pump is generally given by manufacturers' curves or performance tables showing cfm of free air pumped (at rated speed) against inlet conditions ranging from 0 in. Hg (open capacity) to the maximum vacuum rating. The capacity rating at the operating vacuum level is generally used to actually select the size.

Keep in mind that there is some flexibility in sizing selection. If a required type of pump is not available in the required size, then two or more smaller pumps can be teamed to provide the necessa ry capacity.

Purnpdown Rate -The above approach is difficult to apply in many vacuum applications because air removal occurs over a wide range of vacuum levels. Since volumetric efficiency changes with vacuum level, there is no one capacity rating against which the free air requirement can be compared.

One approach to this problem uses the equation:

$$t = \frac{v}{s} \ln \frac{p^*}{p}$$

Here, v is the system volume; p and p* are the initial and f inal pressures, respectively, in absolute units; t is the time available to pump the system from p to p*; and S is the pump capacity in cfm at the actual pressure in the system. If capacities are published in "free air" cfm, as they usually are, they must be converted to "actual pressure" cfm by multiplying by 29.92/(29.92-gauge pressure).

But this procedure leaves open the question of just what capacity S represents. In fact, it is the average capacity between p and p*, a value not readily available. Capacities at intervals of 5 in. Hg are commonly published, however. It is then possible to apply this equation piece-by-piece.

The open capacity is used for pumping down to 2.5 in. Hg, the capacity at 5 in. Hg gauge for p = 2.5 in. Hg gauge and p* = 7.5 in. Hg gauge (remember these numbers must be converted to absolute units), and so on. The pumpdown time thus calculated for a given pump is compared with that required by the application to determine whether the pump has adequate capacity.

Warning Note -Horsepower and displacement should not be used as sizing criteria, since they do not provide accurate measures of the quantity of air actually pumped through the machine.

Other Pump Sizing Factors

After matching the required rate of air removal with available vacuum pump open capacities, the final decision may be influenced by one or more factors.

Effects of Receiver Tank -If a receiver is used with either on/off or load/unload control of the vacuum pump, pump size generally can be smaller because (in most cases) the pump will have a longer time to evacuate a given amount of air.

Sometimes, however, a pump that's otherwise adequate will take too long to initially evacuate the receiver. The time required can be calculated by the method given under "Pumpdown Rate." If this is unacceptable, then a larger pump must be chosen. (Of course, there rarely would be much point in using a receiver if it required a larger pump than would be needed without it.)

In some intermittent-duty applications, it may be desirable to install an extra-large receiver tank to permit a longer off time-a longer cooling period. But this naturally increases the time required for initial pumpdown. If this is unacceptable, one solution is to increase pump capacity. This will reduce both the time required for initial receiver evacuation and the proportion of its duty cycle that the pump spends on.

Effects of Intermittent Duty Cycle -Very short on/off cycles can cause serious problems. When vacuum is controlled by constantly starting and stopping a pump's drive motor, the motor's thermal overload device may be tripped. This will temporarily interrupt the power and result in a pump outage.

If a vacuum/pressure switch is used to control the duty cycle, the off time interval can be extended by either increasing the receiver tank volume or by increasing the range between cut-in and cut-out switch settings. The on portion of the duty cycle can be shortened by increasing pump size.

In general, heavy-duty pumps can operate at maximum vacuum continuously. Light-duty pumps can operate for extended periods of time.

When an intermittent-duty vacuum rating is specified, the restrictions must be strictly observed. Gast intermittent vacuum ratings, for example, are based on a 10-minute on/10-minute off duty cycle. The maximum on period is established so that the pump will withstand the accompanying temperature rise. And the 10-minute off period assures enough time to cool the pump.

Drive Power Selection

A vacuum pump doesn't care how it is driven, so the decision should be based on practical and economic considerations.

After the type and size decisions have been made, based on required vacuum level and flow rate, the job of determining the correct operating speed and horsepower required to drive the vacuum pump is relatively simple. For piston vacuum pumps, a general rule is that about 1 horsepower is needed for each 20 cfm of air pumped.

A major factor in the selection process is deciding whether to have the drive unit mounted directly on the vacuum pump or installed as a separate system element. A third alternative is that the motor can be eliminated if the application provides a rotating shaft, a gasoline engine, or perhaps a special electric motor that will always be running when the vacuum pump is on.

Motor-Mounted Pumps -if a vacuum pump of the required type and size is available with its own integrally mounted electric motor drive, then there is no drive selection problem because the combination is designed to function as a unit. The pump is literally built around the motor.

For example, the rotary vane pump has its rotor installed directly on the motor shaft, and the rest of the pump is securely anchored to the motor frame. There is no need for baseplate mounting or for a power transmission component.

Motor-mounted units are much more compact and lightweight than separate-drive pumps. The end plate on the newer rotary models can be easily removed to expose the vanes for inspection or replacement.

The only drive system problems associated with a motor-mounted pump are those of supplying and controlling the required electrical power. But there is such a wide range of standard and special voltage motors available with the pumps that supply problems are generally minimal. Motor control problems are similar to those in regular heavy-duty industrial applications.

Table 9 lists some representative motor-mounted vacuum pumps. The motor horsepower is included to indicate the range of power requirements.

Separate-Drive Pumps -Separately driven pumps can be connected to the drive unit by either a belt and pulley or a coupling. When powered by belt drives, operating speeds are infinitely variable within design limitations.

Unlike motor-mounted units, a separate-drive system requires an appropriate driving device to generate the required speed and horsepower as established by the pump manufacturer. Vacuum pumps designed for use with separate-drive units are usually foot-mounted. Additional components required for separate mounting, such as baseplates and belt guards, usually can be obtained from the pump manufacturer.

Table 10 lists some representative separate-drive vacuum pumps. Speed and power requirements are included to indicate the kind of basic information the designer needs to develop an effective separate-drive system.

The rated speeds cataloged by vacuum pump manufacturers determine the rate of air removal. At lower operating speeds, both capacity and required horsepower will be proportionately reduced. In general, operation of separate-drive pumps at speeds substantially higher or lower than rated may cause problems. Always contact the pump manufacturer for guidance when the system is to be operated at other than rated speed.

Summary of Vacuum Pump Selection Factors

These basic questions should be answered before deciding which vacuum pump is best suited for a particular application:

• What degree of vacuum is required?

• What flow capacity (cfm) is required?

• What horsepower and speed requirements are needed to meet vacuum level and capacity values?

• What power is available?

• Will duty cycle be continuous or intermittent?

• What is the atmospheric pressure at the work site?

• What is the ambient temperature?

• Are there any space limitations?

Table 7

Vacuum Ratings and Applicable Vacuum Pumps

Max. Vacuum Rating (In. Hg) Continuous	Types of Vacuum Pumps
27.5 to 28.5	Piston (multistage)
25.5 to 29	Rocking piston
24 to 29	Diaphragm (single & multistage)
10 to 28	Rotary vane (oil-lubricated)
15 to 26	Rotary vane (oil-loss)
7	Regenerative peripheral blower

Table 8

Pump Capacities and Applicable Vacuum Pumps

Vacuum Pump Types	Maximum Vacuum Level (in. Hg)		Range of Capacities (CFM Free Air at 0 in. Hg.)	
	Continuous	Intermittent	Smallest	Largest
Piston	27.5-28.5	-	1.3	10.5
Rocking Piston	25.5-29.0	-	1.22	2.7
Diaphragm	23.5-29.0	-	0.49	3.6
Rotary Vane (oil-lubricated)	10-28	25-28	1.3	55
Rotary Vane (Oil-less)	15-27	15-27	0.35	55

Table 9

Availabililty of Motor-Mounted Vacuum Pumps

Vacuum Pump Type	Range of Open Capacities (cfm)	Motor H.P. Requirements
Piston (1-stage) (2-stage)	1.8 to 10.5 cfm 1.15 and 2.30 cfm	1/6 to 3/4 1/8 and 1/4
Rocking piston (1-stage) (2-stage)	1.12 to 1.6 cfm 1.25 to 2.7 cfm	1/8 to 1/4 1/4
Rotary vane (oil-lubricated & oil-less)	0.60 to 10.0 cfm	1/15 to 3/4

Availability of Separate Drive Vacuum Pumps

Vacuum Pump Type	Range of Open Capacities (cfm)	Drive Requirements	
		Horsepower	Speed
Piston	1.3 to 4.8	0.13 to 0.255	200 RPM (minimum 1000 RPM)
Rotary Vane	0.35 to 55	1/40 to 3	800 to 3450 RPM (most common, 1725 RPM)