APPLICATION NOTE

MATCHING PRIMARY AND SECONDARY PUMPS

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Secondary pumps require a primary pump to initially 'prime' them for operation and/or to support their continuous operation. There are several factors which need to be considered for the correct combination or 'matching' of primary and secondary pumps to ensure safe and optimised performance.

The consequences of a wrong selection can be serious, ranging from a 'stalled' diffusion pump (and major oil contamination) to over-heating of a turbomolecular pump.

The following describes these requirements illustrated with common examples.

OVERVIEW

A primary vacuum pump (PP) is one which exhausts to atmospheric pressure. These include oil-sealed rotary vane (OSRV), diaphragm, scroll, multi-stage roots, piston, screw and liquid-ring pumps.

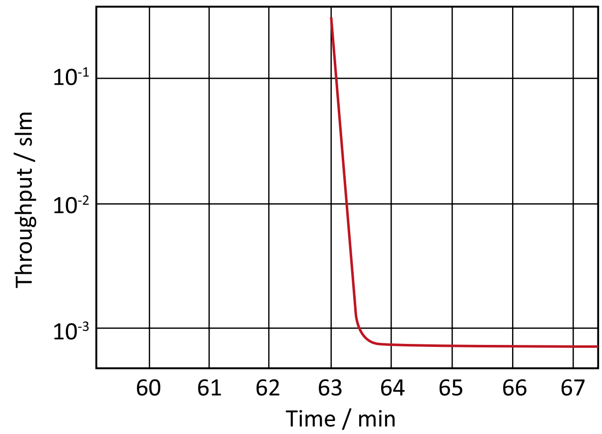
Secondary pumps (SP) require initial evacuation by primary and sometimes other secondary pumps to a required pressure before operation. For example, oil diffusion pumps (ODP), turbomolecular pumps (TMP), vapour boosters (VB), mechanical boosters (MB), ion getter pumps (IGP), titanium sublimation pumps (TSP), non-evaporable getters (NEG), cryogenic, molecular drag and regenerative pumps.

In some cases, supporting backing pumps are required for continuous operation; this is the case for ODP, TMP and VB pumps.

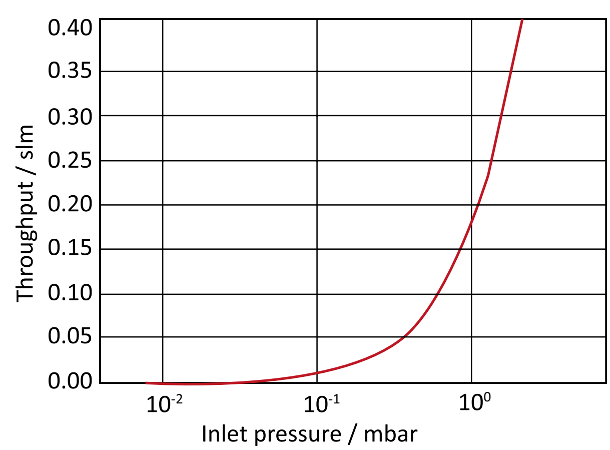
FACTORS TO CONSIDER WHEN MATCHING PRIMARY AND SECONDARY PUMPS

To match a PP and SP, there are several things to consider:

1. Initial pump-down time by the PP to a point where the SP 'takes over' the pumping process. This is especially important if the SP starts at the same time as the PP and a given pressure must be reached in a given time to prevent the SP from 'timing' out.
2. Initial 'surge' of gas flow and pressure spike when the SP starts. This is illustrated by the figure below where an nXDS15i scroll is the PP and an nEXT300D is the secondary TMP; the spike in throughput corresponds to the rise in pressure when the SP (nEXT300D) 'takes-over' the pumping.



This would give a corresponding rise to ~1.5 mbar in the PP as shown below:



3. Maximum Backing Pressure (MBP) / Critical Backing Pressure (CBP) should not be exceeded. This puts a limit on the maximum gas flow. The PP must have sufficient speed performance at the required backing pressure rather than assuming the peak/nominal speed of the PP.
4. The MBP value may be quoted by the manufacturer for zero flow rather than with flow.
5. Cleanliness (is a dry pump required?).
6. Does the PP need to be intergratable with the SP?
7. What is the typical residual atmosphere of the PP – particularly when combined with TMPs with respect to compression? This is important since for example the relatively low compression ratio of a TMP for H_2 may limit its achievable ultimate pressure if the H_2 partial pressure in the backing pump is significant.

ILLUSTRATIONS

There are many possible combinations of PP and SP each with their own specific requirements. To illustrate this some common-place examples are described below:

Oil Diffusion Pumps

As discussed previously, an incorrect combination of PP with an ODP can lead to the stalling of the ODP's supersonic oil jets and back-streaming of oil into the volume been pumped by the ODP, with a consequent major contamination event. Hence the backing pressure (Pb) must be kept below the critical backing pressure (CBP) of the ODP at all times.

i.e. we require: P_b < CBP
and since CBP = Q_{max}/S
where Q_{max} is the maximum allowable throughput and S is the backing pump speed
then the minimum pumping speed is $S_{minimum} > Q_{max}/CBP$

Example 1: ODP - Diffstak 250/2000

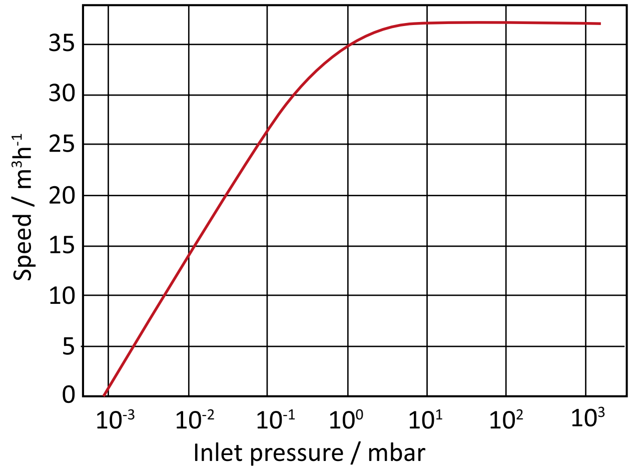
The catalogue specifications for this pump are shown below:

TECHNICAL DATA

Pumping speed Nitrogen Hydrogen	 2000 l s^{-1} 3000 l s^{-1}
Min backing pump displacement*	40 m^3h^{-1}
Recommended backing pump	E2M40
Recommended fluid	Santovac® 5
Fluid charge (dry)	500 ml
Inlet connection compatible with	ISO250
Backing connection	NW40
Cooling water connection	10 mm compression fittings
Heater power	2.25 kW
Min cooling-water flow at 20°C	180 l h^{-1}
Pneumatic connections†	6mm coupling x ¼ BSP male stud
Pneumatic acuating pressure Minimum Maximum	 2.4bar / 35psi 6.9bar / 100psi
Weight 250/2000M 250/2000P	 59kg 60kg

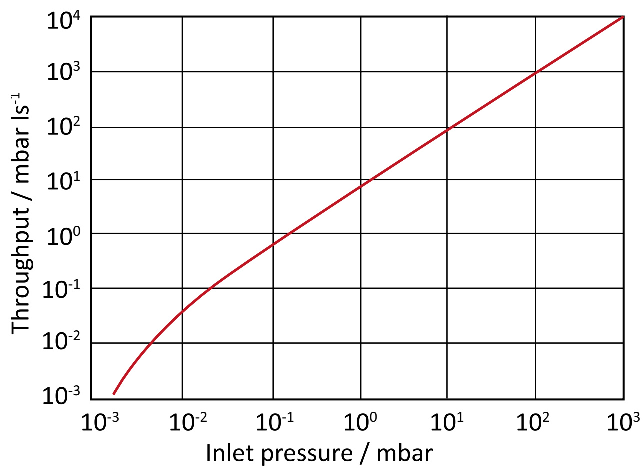
* For maximum throughput † 250/2000P only

The CBP for Silicone DC702 oil is 1.2 mbar and an E2M40 OSRV PP is recommended; its performance is shown below:



E2M40 speed curve

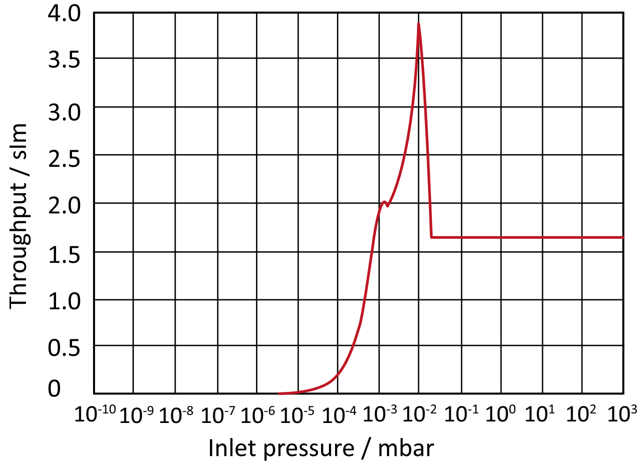
This can be re-expressed in terms of throughput as below:



E2M40 throughput curve

It can be seen that at 1.2 mbar backing pressure the E2M40 throughput is ~12 mbarl/s.

The throughput curve for a 250/2000 diffstak is shown below:



From this it can be seen that the maximum throughput for the 250/2000 is 4 mbarl/s. So, we can conclude that there is a safety margin (factor of ~3) in using an E2M40.

Example 2: Edwards HT20B

This has a maximum stated throughput = 24 mbarl/s and its CBP = 1.3 mbar
thus $S_{minimum}$ > 67 m³/h
The quoted minimum backing pump displacement = 135 m³/h (~ 2 x $S_{minimum}$)
and the recommended pump is GV160 or E2M175 with operating pressures for a throughput = 24 mbarl/s of 0.7 mbar and 0.6 mbar respectively.
From both these considerations it can be concluded that this approach gives a safety margin of x 2 thus:
$S_{minimum} > 2 \times Q_{max}/CBP$

Cryopumps

A wrong matching PP can considerably increase the start-up time of the Cryopump and result in incomplete regeneration.

A PP needs to make the initial pump down of the Cryopump to 0.01 mbar before commissioning it.

By definition the Cryopump's Crossover Value CV = P_c x V (where P_c is the cross-over pressure and V is the volume being pumped) allows the calculation of the pressure which must be achieved before exposing the Cryopump to pump a given volume i.e. crossing-over from the PP is stated in mbar x litres (hence P_c is inversely proportional to the volume being pumped).

For example, the Edwards CTI CryoTorr 4F Cryopump
Crossover value = 100 torr.litre
Hence for a volume of 100 litre
P_c = 1 torr
and
for a volume of 1000 litre
P_c = 0.1 torr

There are two general PP requirements during Cryopump regeneration

1. Typically water vapour tolerance should be > 10 mbar.
2. Ultimate pressure should be < 0.04 mbar or < 8e-3 mbar when regenerating hydrogen – (also need to ensure safe configuration) or <1e-4 mbar for UHV.

Turbomolecular pumps

There are several factors to consider when matching a PP and TMP

1. The PP should have sufficient capacity and ultimate vacuum to achieve a pressure which the TMP can be started from, or can reach full speed, in a short enough time interval. This is especially important when the TMP is started at the same time as the PP, considering that the TMP could 'time-out'.
2. The PP keeps below the maximum continuous backing pressure (MCBP). This is to avoid the TMP overheating and potentially slowing down or stopping.

The MCBP value is often stated for the case of zero-flow (or throughput) conditions (i.e. at ultimate inlet pressure). During flow conditions, the MCBP will be significantly lower than the former stated value.

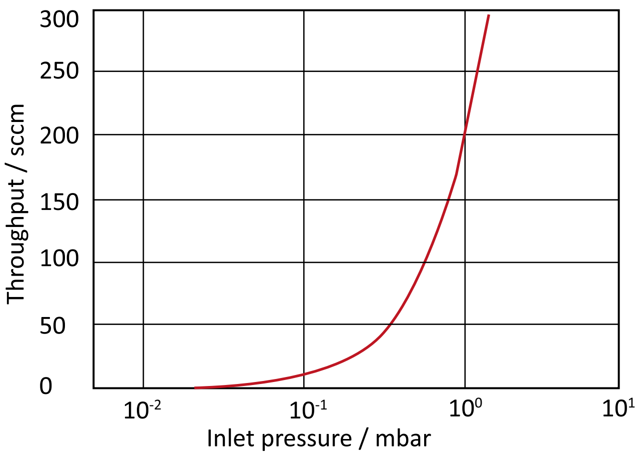
For example, an Edwards nEXT85 operating parameters are shown below:

Parameter	Force air cooling (20 °C ambient)	Natural covection (35 °C ambient)	Force air cooling (40 °C ambient)	Water cooling (40 °C ambient)
Maximum continuous backing pressure (at ultimate inlet pressure) § (mbar)	18	10	11	17
Maximum input flow sccm:				
N_2	60	22	25	42
He	232	96	128	191
Ar	21	7	7	15

* Cooling water temperature 15 °C at a flow rate of 15/hr[1]

§ Values for maximum continuous inlet pressure obtained using an nXDS15i backing pump at sea level in a negligible magnetic field. Values for maximum continuous backing pressure obtained under no-flow conditions at sea level in negligible magnetic field. Refer to Cooling on page 32 for cooling conditions. Above these pressures, rotational speed drops below nominal.

From the throughput curve of an nXDS15i below, we can see that the MCBP for an input flow of 60 sccm is 0.4 mbar. This is much less than the stated MCBP of 18 mbar at zero throughput (with forced-air cooling).



nXDS15i throughput curve

An Edwards STP-A2203 pump can be considered for another example.

The STP-A2203 stated maximum allowable N_2 flow rate is 1,500 sccm and its maximum allowable backing pressure is stated as being 4 mbar.

However, a backing pump (PP) of capacity = 1,300 l/min is stated as being required;
1,500 sccm = 1,631 mbar.l/min.
thus a backing pump (PP) speed of 1,300 l/min would give a backing pressure of
1,631/1300 = 1.3 mbar which is over a factor of 3 lower than the maximum allowable backing pressure.

Ion Getter Pumps

There are two considerations to be made for operation. Firstly, the IGP and chamber it will be evacuating must be pumped down to a low enough pressure before the IGP is turned on (or 'strikes').

Secondly, to maximise the lifetime of the pump the PP/SP should achieve a low enough pressure (High Vacuum) before the IGP is operated.

For example a Gamma Vacuum Titan CV 100L pump has specifications as shown below:

SPECIFICATION

Weight	29 (65) kg (lbs)
Shipping weight	47 (105) kg (lbs)
Ultimate pressure	less than 10^{-11} mbar
Lifetime	50,000 hours @ 1e-6 mbar
Operating bake temperature	250 °C
Maximum bake temperature	450 °C without magnets
Dimensions (l x w x d)	326 x 128 x 252 mm

Whereas the starting pressure is stated as being 10^{-3} mbar, in practice continued operation at heightened pressures can affect the lifetime of the pump, especially if the system is vent-cycled often. The lifetime of the pump is 50 hours at 1e-3 mbar.

Here in this case the PP would actually need to be a combination of a PP and SP – a TMP/PP being the most commonly used 'pre-evacuation' configuration.

CONCLUSION

The correct matching of primary and secondary pumps is important to ensure safe and optimized operating conditions.

Each potential combination should be addressed separately as each has specific requirements. Consideration should be made to the actual meaning of manufacturers' specifications.

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