Sizing Differential Pressure Regulators in Seal Oil Service for Turbomachinery

Selecting the proper differential pressure regulator can sometimes be perceived as a confusing prospect. Differential pressure regulator applications usually have operating conditions outside of what is normally seen in standard pressure regulating operations, which means more variables must be taken into account when sizing and selecting a pressure control device.

Differences between Standard and Differential Control

Standard, self-operated regulators are self-contained valve and actuator combinations that rely on three essential elements to control pressure either downstream (pressure reducing) or upstream (backpressure) of the valve.

The three elements a regulator uses are: a valve plug and seat to control flow, a diaphragm to measure system pressure and a spring to load the diaphragm and provide a force balance to create a regulator set point. Figure 1 shows a diagram depicting the three essential elements in both a pressure reducing and backpressure regulator.

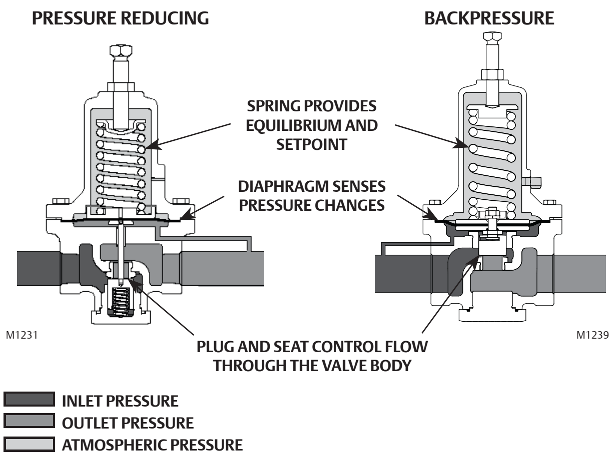

Figure 1. **Essential Elements of a Standard Pressure Controlling Regulator**

Differential control regulators operate in much the same way as a standard regulator, however they have an additional loading pressure added to the top of the regulator diaphragm, which increases the force and raises the set point of the unit. Figure 2 details the loading pressure applied to the differential control regulator for both pressure reducing and backpressure service.

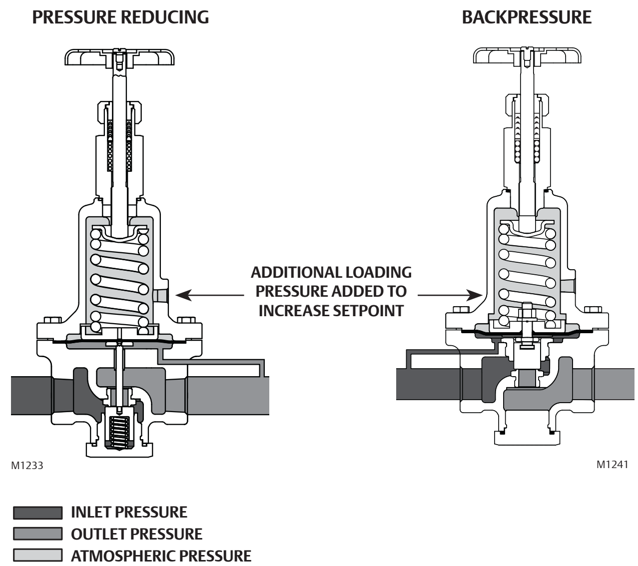

Figure 2. **Elements of a Differential Pressure Controlling Regulator**

Seal Oil in Turbomachinery

One application where it is fairly common to see differential pressure regulation is in seal oil systems for large rotating equipment like compressors or pumps. In these systems pressurized oil is used in the seals to keep process fluid from leaking out of the machine via the shaft.

The benefit of using a differential pressure regulator in this application is that the regulator is always sensing the reference pressure coming from the inner seal, which means the regulator can make immediate flow corrections when it senses a pressure change in the reference fluid pressure.

In the case of seals, the purpose of the regulator is to provide a supply of oil at a pressure slightly higher than that of the process fluid inside of the machine.This difference in pressure is maintained by the reference pressure, which comes from the inner seal, and the spring force provided by the regulator setpoint.

There are two common methods for controlling this differential pressure: forward pressure control or backpressure control. Both of these methods are viable at accurately controlling seal oil pressure, but the forward pressure control method is more prevalent.

Forward Pressure Control

Forward pressure control uses a pressure-loaded pressure reducing regulator that will use the pressure of the reference gas to increase the set point of the regulator. An example seal oil system with forward pressure control is detailed in Figure 3.

Before start-up of the pump or compressor, the seal oil system is started to allow oil to enter the seals. Because there is no loading pressure being added to the regulator, the pressure reducing regulator is controlling downstream pressure to the initial regulator setpoint. Figure 4 shows the process conditions across an example regulator during oil pump startup.

Once the seal oil system is running, the rotating equipment will be started and the pressure in the regulator spring case will begin to increase. As a result the regulator set point will begin to rise and the new setpoint of the regulator will become the spring set point plus the reference gas pressure.

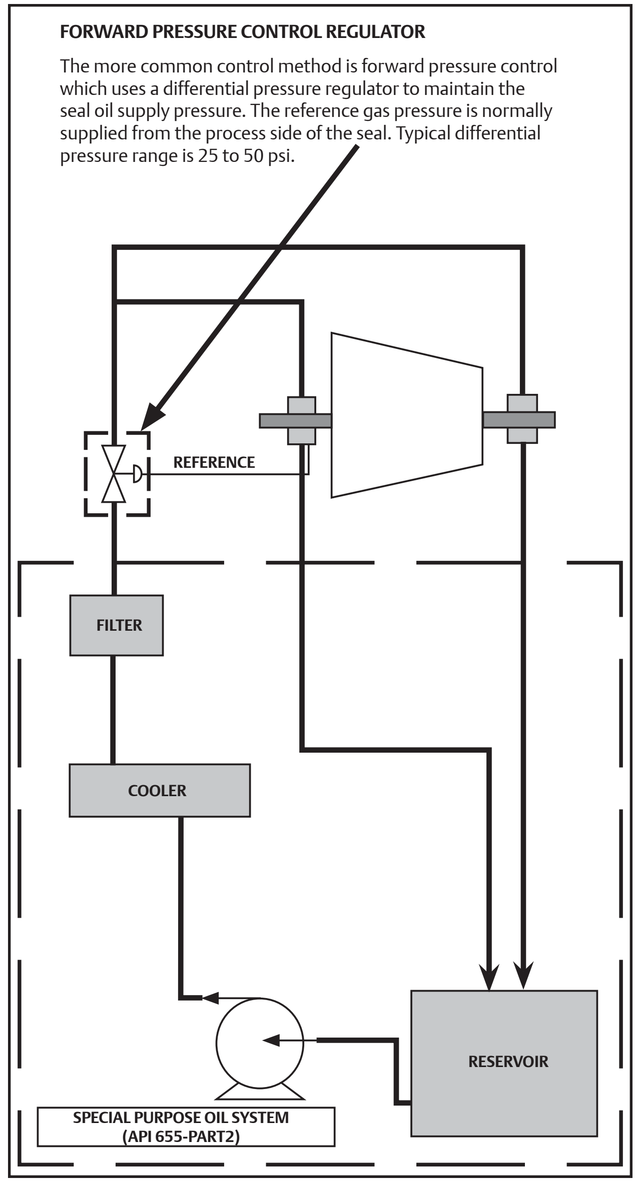

Figure 3. **Example of Forward Pressure Control Using a Differential Regulator**

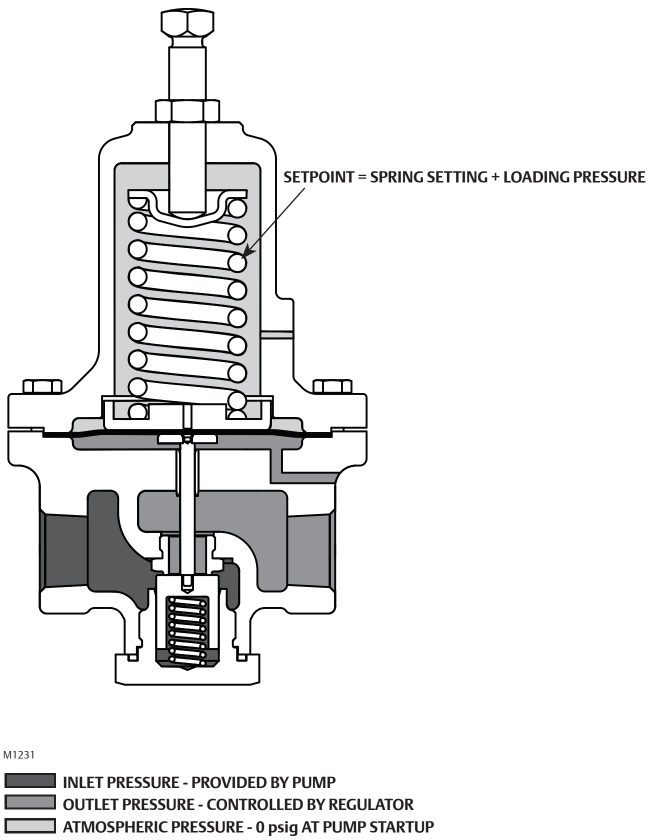

Figure 4. **Pressure Reducing Regulator at Startup**

Backpressure Control

Backpressure control is the second method that can be used to control differential pressure. An example of backpressure control is shown in Figure 5. In backpressure control the regulator is placed on the downstream side of the seals, sensing pressure upstream of the regulator coming from the seals. As the pressure through the seals begins to increase to the regulator set point, the backpressure regulator will start to open and allow excess pressure to relieve downstream, keeping the pressure through the seals constant.

Similar to forward pressure control, this control method will also utilize differential control using the reference pressure provided from the inner seal.

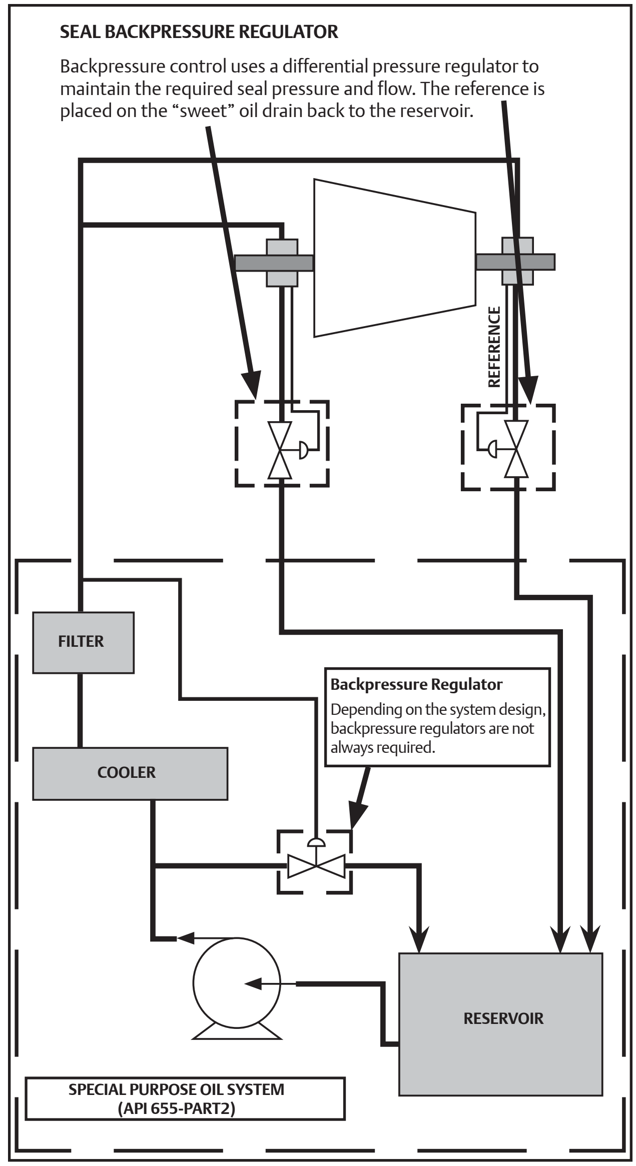

Figure 5. **Example of Backpressure Control Using a Differential Regulator**

Pressure Loaded Regulator Mechanics

Sizing a differential regulator for seal oil service can be challenging since the manufacturer's literature frequently does not include set points as high as the combined spring load plus loading pressure. For example, the capacity tables for the Type MR95HD only have data for pressure settings up to 150 psig. Fortunately, the addition of loading pressure has no effect on the regulator flow coefficient, otherwise known as its regulating C_v value. The regulating C_v is characterized by the regulator body and the initial spring setting of the regulator, and the addition of loading pressure provides a force balance across the regulator. This keeps the regulating C_v value dependent upon the initial spring setting.

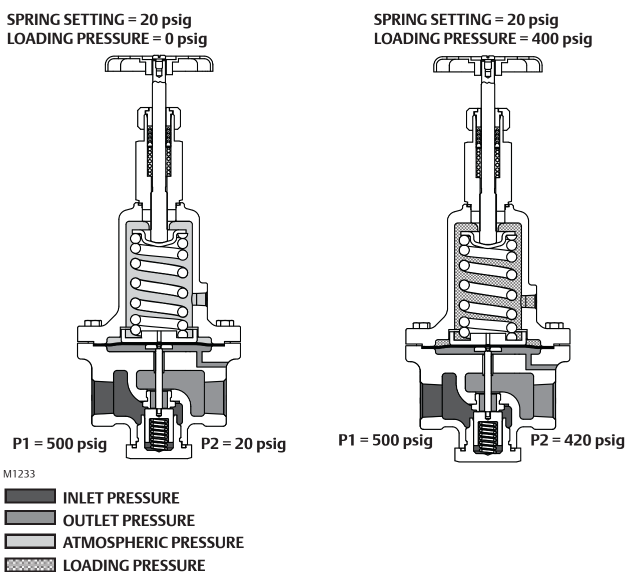

Figure 6. **Pressure Conditions in Differential Pressure Regulators Pre- and Post-Compressor Startup**

Consider the two regulators shown in Figure 6. The regulator on the left uses spring load only to make a setpoint of 20 psig. The regulator on the right uses the same spring load plus a pressure load of 400 psi to make a set point to 420 psig. At 4 psid droop (or 20% droop off spring setting), the regulator on the right flows much less than the regulator on the left since the differential pressure across the valve is considerably less. However, when the C_v coefficients are calculated for each regulator, the values are the same.

This is because even though the inlet pressures and setpoints are different, the pressure differential between the inlet pressure and the loading pressure is the same. Both regulators in Figure 6 are open the same amount and therefore have the same C_v value. Therefore, the C_v tables in the product bulletin can be used to size a differential regulator the same way you size a standard pressure reducing application.

The same principle applies when sizing a backpressure regulator. Figure 7 details pre- and post-compressor startup conditions for a backpressure regulator and shows that fundamentally the regulator still operates in the same manner detailed above.

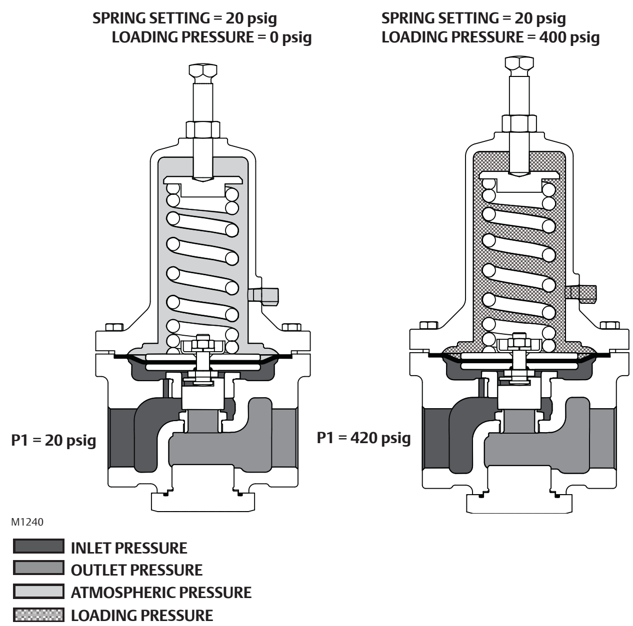

Figure 7. **Pressure Conditions in Differential Backpressure Regulators Pre- and Post-Compressor Startup**

One key difference in backpressure operation is that as the loading pressure increases, the differential pressure across the valve itself also increases. This is inverse to the pressure reducing example from Figure 6. In liquid service, maximum flow is proportional to pressure differential. In forward pressure reducing regulators, as loading pressure increases, maximum flow decreases. In backpressure regulators, maximum flow increases when loading pressure increases.

Sizing a Seal Oil Regulator for Forward Pressure Control

Below is a step-by-step guide for sizing a differential pressure regulator using a Type MR95HDP in seal oil service. We will be using the pressure conditions from Figure 6 as the basis for our sizing example. We will also be making the assumption that the inlet pressure to the valve will remain fairly constant, but the outlet pressure will change based upon pre- and post-compressor startup conditions.

Step 1. Establish Inlet and Outlet Conditions, along with flow requirements

Table 1. **Example Requirements for Sealing Oil Regulator-Forward Differential Control**

BACKPRESSURE SERVICE SIZING CONDITIONS	PRE-COMPRESSOR STARTUP	POST-COMPRESSOR STARTUP
Flow	80 GPM	80 GPM
Inlet Pressure	500 psig 514.7 psia	500 psig 514.7 psia
Outlet Pressure	20 psig 34.7 psia	420 psig 434.7 psia
Spring Set Point	20 psig	20 psig
Loading Pressure	0 psig	400 psig
Specific Gravity	0.85	0.85

Step 2. Use the general liquid sizing equation to establish C_v requirements

$$C_v = \frac{Q}{\sqrt{\frac{\Delta P}{G}}}$$

Equation 1: Liquid Sizing Equation

where:

C_v = Valve sizing coefficient determined using water at standard conditions

Q = Flow in gallons per minute

ΔP = Pressure differential in psia

G = Specific gravity of the fluid media

Table 2. **Required C_v Calculations**

PRE-COMPRESSOR STARTUP	POST-COMPRESSOR STARTUP
$C_v = \frac{80\ GPM}{\sqrt{\frac{480\ psi}{0.85}}}$	$C_v = \frac{80\ GPM}{\sqrt{\frac{80\ psi}{0.85}}}$
$C_v = 3.37$	$C_v = 8.25$

Notice that the post-compressor start-up C_v is our "worst case" scenario for flow rate requirements, and as long as a valve can meet this flow at the given post-compressor startup conditions then the valve will be able to satisfy the full flow range requirement.

Step 3. Use bulletin data provided by the regulator manufacturer to determine regulating C_v at the spring set point condition. In the above case, it is more important to size based on the higher required C_v, which is post-compressor startup conditions.

Table 3. **Type MR95HDP C_v Data for 20 psig Spring Setting**

BODY SIZE	SPRING SETPOINT	DIFFERENCE IN INLET PRESSURE AND SPRING SETTINGS	PRESSURE DROOP FROM SPRING SETTING, psig	
			C_v	
In.	psig	psig	10%	20%
1-1/2	20	80	4.2	6.4
2	20	80	8.1	14.1

Selecting a 2 in. Type MR95HDP regulator would allow the application to be adequately sized, while allowing less than 20% droop at the post-compressor startup condition.

Sizing a Seal Oil Regulator Using Backpressure Control

Below is a step-by-step guide for sizing a differential pressure regulator using a backpressure regulator. We will use the Type MR98HDP as our backpressure regulator for this case, and the pressure conditions from Figure 7 for our sizing example.

Step 1. Establish Inlet and Outlet Conditions, along with flow requirements

Table 4. **Example Requirements for Sealing Oil Regulator-Backpressure Control**

BACKPRESSURE SERVICE SIZING CONDITIONS	PRE-COMPRESSOR STARTUP	POST-COMPRESSOR STARTUP
Flow	80 GPM	80 GPM
Inlet Pressure	20 psig 34.7 psia	420 psig 434.7 psia
Outlet Pressure	0 psig	0 psig
Spring Set Point	20 psig	20 psig
Loading Pressure	0 psig	400 psig
Specific Gravity	0.85	0.85

Step 2. Use the general liquid sizing equation to establish C_v requirements

$$C_v = \frac{Q}{\sqrt{\frac{\Delta P}{G}}}$$

Equation 1: Liquid Sizing Equation

Table 5. **Required C_v Calculations**

PRE-COMPRESSOR STARTUP	POST-COMPRESSOR STARTUP
$C_v = \frac{80\ \text{GPM}}{\sqrt{\frac{20\ \text{psid}}{0.85}}}$	$C_v = \frac{80\ \text{GPM}}{\sqrt{\frac{420\ \text{psid}}{0.85}}}$
$C_v = 16.5$	$C_v = 4.05$

Step 3. Use bulletin data provided by the regulator manufacturer to determine regulating C_v at the spring set point condition. Again, we size based on the higher C_v requirement which in this case is pre-compressor startup conditions. This is in direct contrast to the forward pressure control method.

Table 6. **Type MR98HDP C_v Data for 20 psig Spring Setting**

BODY SIZE	SPRING SETPOINT	PRESSURE BUILDUP OVER RELIEF PRESSURE SETTING, PSIG		
		C_v		
In.	psig	5	7	10
1	20	5.1	5.5	6.3
2	20	12.6	14.5	16.9

Selecting a 2 in. Type MR98HDP regulator would allow the application to be fully sized at the pre-compressor condition, while a 1 in. Type MR98HDP regulator would satisfy flow requirements at the post-compressor startup condition. To satisfy both pre- and post-compressor startup conditions the 2 in. Type MR98HDP must be selected. It is important to take note of the large difference in required C_v, as this will affect turndown requirements. Fortunately self-operated valves like the Type MR98HDP typically have larger turndown ratios and are able to regulate flow in both low and high flow conditions.

Summary

Differential control does add some unique challenges when sizing and selecting a pressure regulator. Fluctuating process conditions must be taken into account and can be a source of confusion; however it is important to take note that the general operating principle of the regulator remains the same. Differential control can provide benefit in systems like seal oil pressure control by giving the regulator the ability to increase or decrease the set point based on process conditions, without requiring manual input from an operator or control system. This guide can help provide some clarity in selection of a differential regulator, and be used as a tool to ensure your differential control equipment is correctly sized from the onset of a project.

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