Creating a compact and environmentally friendly pressure regulator with filter

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Key words

Pressure regulator with filter, compact and lighter weight, environmentally friendly design, pressure control

The user-friendly model KZ03 pressure regulator has enjoyed wide use and continuing sales over an extended period. Its sister model, the RA1B pressure regulator, is designed for high reliability, extra long-term operation, and enhanced stability of pressure control through the improvement of mechanisms such as the guide O-ring and suction tube. With reduced air consumption and miniaturization to about 70 % of the conventional size, it is also.

1. Introduction

Azbil's Advanced Automation business provides measurement and control devices to factory and plant markets in various fields, including petrochemistry, electric power, and gas.

Among these devices, control valves, positioners, controllers, and other products use pneumatic pressure as the driving force.

A pressure regulator plays the role of supplying stable pressure by reducing the supplied high-pressure air down to the rated pressure of the individual devices.

Azbil's current product model KZ03 pressure regulator, which launched 40 years ago, is a long-running product. Due to the increasingly diversified range of products it is used with, there is a demand for improved stability in its pressure control. In response, Azbil has developed a new pressure regulator with filter, model RA1B. It is designed to use fewer resources for environmental friendliness and to be more compact and lightweight.

Figure 1 shows the old and new models. Both have a 40 mm pressure gauge, although the RA1B itself is smaller.

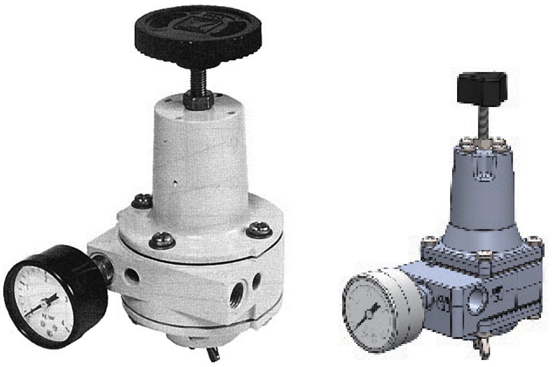

Fig. 1. Pressure regulator models KZ03 (left) and RA1B (right)

2. Operating principle of a pressure regulator

2.1 Structure and operating principle of a pressure regulator

The air that enters from the primary side goes through the filter, which filters out foreign substances, and then through the valve, and then is output from the secondary side.

If the force of the output pressure (secondary pressure) pushing up on the diaphragm balances the force of the pressure control spring pushing down on the diaphragm, the primary side of the valve closes.

If the secondary pressure exceeds the set pressure, it overcomes the force of the pressure control spring and lifts up the diaphragm, which creates a gap between the diaphragm and the top of the valve, allowing air to be discharged to the atmosphere through a bleed hole in the side of the bonnet.

Figure 2 shows the structure of a pressure regulator.

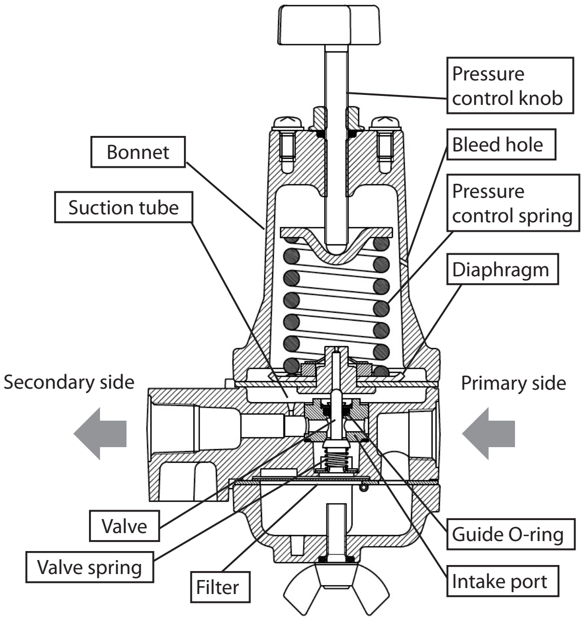

Fig. 2. Structure of a pressure regulator

2.2 Characteristics of pressure regulators

The main characteristics of a pressure regulator include flow characteristics and pressure characteristics. With these characteristics in mind, the design of the unit must consider various elements, including the flow channel arrangement and the mechanical properties of the components.

The flow characteristics and pressure characteristics can be derived from the equation for the equilibrium of the pressure control spring and the secondary pressure shown below.

In figure 3, assuming that F_1 is the force of the secondary pressure pushing up on the diaphragm and that F_2 is the force of the pressure control spring pushing down on the diaphragm, these forces can be expressed as follows.

$$F_1 = P_1B + P_2A + k_b\delta_b \qquad \text{Equation (1)}$$

$$F_2 = P_2B + k_a\delta_a + mg \qquad \text{Equation (2)}$$

Here, the supply pressure (primary pressure) and the secondary pressure are P_1 and P_2 respectively, the spring constant of the pressure control spring and its amount of deflection are k_a and δ_a respectively, and the spring constant and deflection of the valve spring that presses the valve from the bottom are k_b and δ_b respectively. Additional elements are the valve load m, effective area of the diaphragm A, cross-section of the throat B, and gravitational acceleration g.

When the upward force F_1 and the downward force F_2 balance, they can be expressed as follows.

$$P_1B + P_2A + k_b\delta_b = P_2B + k_a\delta_a + mg \qquad \text{Equation (3)}$$

From the above equation, P_2 can be expressed by equation (4).

$$P_2 = \frac{(-P_1B + k_a\delta_a - k_b\delta_b + mg)}{(A - B)} \qquad \text{Equation (4)}$$

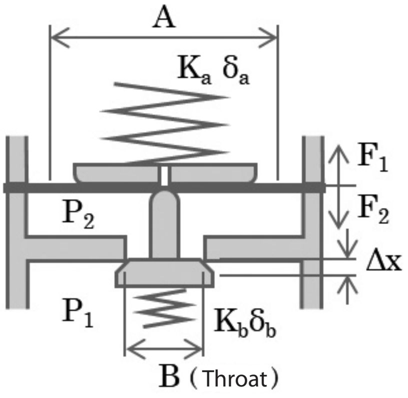

Fig. 3. Schematic diagram of the pressure regulator

2.2.1 Flow characteristics

Flow characteristics represent how the pressure fluctuates from the set value according to changes in the flow on the secondary side.

For stable control of a pressure regulator, it is desirable for changes in the secondary pressure to be small even when the flow rate changes.

When the secondary pressure is the set value P_2 and the valve is closed, if the secondary pressure decreases, the valve will open to supply pressure. Since the deflection of the spring changes during this process, a new balance is struck and the secondary pressure becomes P_2'. When the degree of valve opening, Δx, is put in equation (4), P_2' can be expressed as follows.

$$P_2' = \frac{\{-P_1B + k_a(\delta_a - \Delta x) - k_b(\delta_b + \Delta x) + mg\}}{(A - B)} \qquad \text{Equation (5)}$$

The change in the secondary pressure ΔP_2 can be derived by subtracting equation (4) from equation (5) as follows.

$$\Delta P_2 = P_2' - P_2 = \frac{-(k_a + k_b)}{(A - B)}\Delta x \qquad \text{Equation (6)}$$

When the valve opens, the flow increases, so the relationship between the changes in the flow rate and pressure can be understood from equation (6). The items other than Δx on the right side are constants determined by the design of the pressure regulator. Since the direction in which the valve opens is set to be negative in the calculation, Δx is a negative value. Accordingly, equation (6) indicates that the secondary pressure will decrease as the flow increases when the valve opens and that the factors are determined by the spring constant and the area of the diaphragm and the throat.

The small effective area of diaphragm A in the RA1B as a result of its reduced size is disadvantageous in terms of characteristics.

2.2.2 Pressure characteristics

Pressure characteristics represent how much the secondary pressure fluctuates in response to fluctuations in the primary pressure.

As in the case of flow characteristics, for stable control it is best that the secondary pressure is not readily affected by fluctuations in the primary pressure.

Consider the case where the primary pressure P1 changes by ΔP_1 in equation (4) above.

When the secondary pressure P_2 becomes P_2", it can be expressed as shown below.

$$P_2'' = \frac{\{-(P_1 + \Delta P_1)B + k_a\delta_a - k_b\delta_b + mg\}}{(A - B)} \qquad \text{Equation (7)}$$

The fluctuation in the secondary pressure ΔP_2 is expressed as follows.

$$\Delta P_2 = P_2'' - P_2 = \frac{-B}{(A-B)}\Delta P_1 = \frac{-1}{(A/B-1)}\Delta P_1 \quad \text{Equation (8)}$$

Based on equation (8) above, the pressure characteristics are determined by the ratio of the effective area of the diaphragm A to the area of the throat B. The value of A/B is rather large, which means that the pressure regulator suppresses fluctuation in the primary pressure.

3. Characteristics desired for a new type of pressure regulator

Eventually, a pressure regulator will develop problems in operation and become unable to control pressure to a steady value due to air leakage resulting from wear or misalignment of components such as the valve.

Although aspects of the KZ03's structure, such as the valve misalignment prevention mechanism, have been simplified, the design of the RA1B pressure regulator improves its pressure control stability compared to model KZ03.

Since the KZ03 and RA1B are pneumatically driven, and the consumption of air is regarded as an environmental indicator, it was necessary to reduce wasteful air consumption.

Both models are bleed type valves, which means that the valve does not fully close for improved response performance to changes in the secondary pressure. Although air consumption cannot be reduced to zero, the RA1B's structure reduces wasteful air consumption to less than that of the KZ03.

In addition, since the devices into which a pressure regulator is incorporated are getting smaller, we aimed for the volume of the RA1B to be 70% or less of the volume of the KZ03. However, as we indicated above, a larger diaphragm area is more advantageous in terms of flow and pressure characteristics. For that reason, while reducing the size of the RA1B, we incorporated an inventive idea involving a suction tube described below to achieve a good balance between various characteristics.

4. Technology of model RA1B

When developing the RA1B, we reviewed the specifications and design of the valve and every other component with the aim of improving the stability of pressure control, reducing air consumption, and creating a more compact product.

Among other elements, this article describes the design of the guide O-ring, valve, and suction tube.

Figure 4 shows an enlarged view of the relevant section.

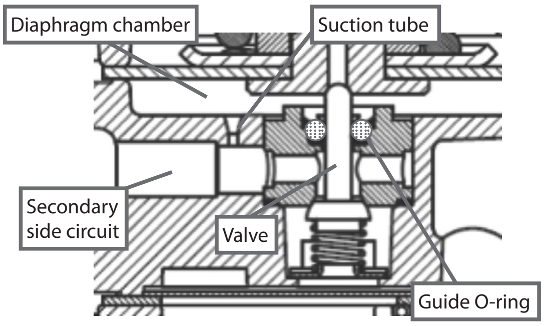

Fig. 4. Enlarged structural drawing

4.1 Guide O-ring

In the KZ03, the valve guide hole does not come into contact with the valve. In the RA1B, to reduce excessive air consumption, an O-ring-based contact-type guide is provided so that the valve closes securely without becoming misaligned.

The O-ring is affected by sliding friction due to the up and down movement of the valve, so wear was a concern. Generally, rubber with improved wear resistance is used in such a situation, but it hardens under low temperatures, which may obstruct the movement of the valve. For that reason the RA1B incorporates a type of rubber that has low frictional resistance and maintains elasticity even at low temperatures, so that it is unlikely to obstruct sliding motion.

The resulting structure has high long-term reliability and shows no wear of the O-ring even over a period of sliding motion that significantly exceeds the design life.

4.2 Valve roller burnishing process

The valve used in a pressure regulator is a single rod-like component. In this product the valve has a hemispherical shape at the tip and a shoulder-like enlargement at the base. The valve's tip and shoulder sections cover the pneumatic circuit to shut off and seal unnecessary air flow. If the surface of these sections is not smooth, lack of airtightness will cause the air consumption to increase. In the case of extreme leakage, it would not be possible to control the pressure.

Generally, electrolytic polishing is an effective way to make a metal surface smooth.

Electrolytic polishing refers to the surface treatment described below.

When a metal is processed into a valve shape by cutting, fine uneven patterns of grooves and ridges are cut into the surface. When a part processed in this way is immersed in a chemical liquid and voltage is applied—turning the part into an electrode—the metal is ionized and dissolved. The first parts of the metal to dissolve are the protrusions, resulting in a smooth surface.

Electrolytic polishing is often used to achieve a mirror finish, but it creates an environmental burden due to the need to treat the waste liquid, etc. We therefore searched for an alternative for use on the RA1B.

We first checked how the valve operated after only cutting it on a lathe, but before airtightness could even become an issue, the guide O-ring pushed into the grooves in the valve's surface, causing the valve to seize up so that the pneumatic circuit would not open or close. We then added a burnishing process after cutting.

Burnishing refers to smoothing out the unevenness of a surface by pressing a roller tool against it. With only cutting, the arithmetic mean estimation of the surface roughness was about Ra0.8, but after burnishing it was about Ra0.2, which can be considered a mirror finish.

Since electrolytic polishing is no longer necessary thanks to this method, we have prevented the use of chemical liquids that put a burden on the environment. In addition, rod-like components such as a valve can be completed by a single turning process that transitions from cutting to burnishing, which also has advantages in terms of cost and finish quality.

Figure 5 shows an enlarged image of the surface before and after burnishing. Before burnishing, grooves are clearly visible. After burnishing, however, the surface is more even and the grooves are hard to see.

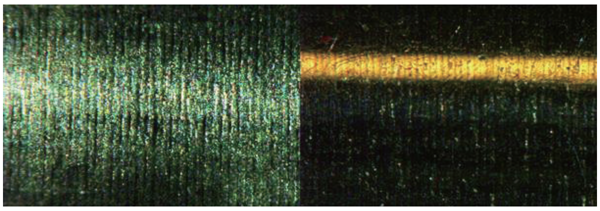

Fig. 5. Before (left) and after (right) burnishing

4.3 Suction tube

In the KZ03, there is a large space under the diaphragm. Since the secondary pressure is directly drawn into this space, this structure is likely to cause a turbulent flow and is susceptible to changes in pressure.

In the RA1B, the diaphragm chamber and the secondary pressure pneumatic circuit are divided but connected by a narrow hole called a suction tube. The potential benefits of this structure include improved responsiveness thanks to the reduced volume of the diaphragm chamber, improved stability thanks to reduced turbulent flow, and more.

The suction tube itself is also effective in improving responsiveness by reducing pressure, since it efficiently sucks air out of the diaphragm chamber by means of the flow on the secondary side.

The suction tube is more effective in sucking out the air at a higher flow velocity, which helps to improve the flow characteristics that were lowered by the compact size of the product. To enhance the effect of the suction, the most effective way would be to have an L-shape pipe in the secondary flow path with the pipe opening oriented downward. However, the compact size of the RA1B makes a pipe difficult. Since the pipe itself would narrow the secondary flow path, in this model the diaphragm chamber and secondary pressure flow path are simply connected by a hole.

In the course of development, we conducted flow analysis along with prototype evaluation on the effects of the design described above to determine the best shape.

There are two types of fluid analysis: steady-flow analysis and unsteady-flow analysis. Since it is difficult to observe transient states and the responsiveness benefits cannot easily be checked by steady-flow analysis, we used unsteady-flow analysis to observe pressure tracking at each flow path section by changing the secondary pressure over time.

Figure 6 shows one of the models analyzed, and figure 7 shows a sample analysis of the pressure distribution and flow velocity around the suction tube.

As a result of analyzing a total of over 20 models, we were able to choose an appropriate flow path shape while significantly reducing the testing time with actual devices.

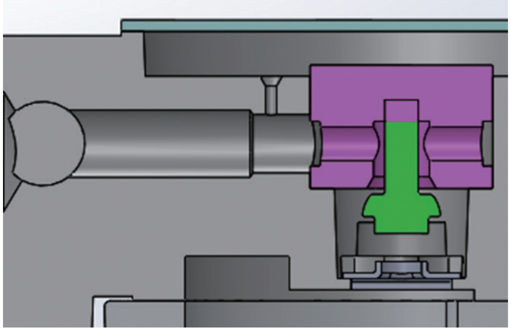

Fig. 6. Example of one of the analyzed models

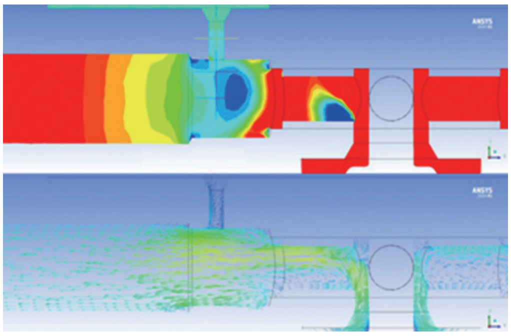

Fig. 7. Sample results of analysis (top: pressure; bottom: flow velocity)

5. Summary

By adopting a guide O-ring to prevent misalignment of the valve, we improved the airtightness of model RA1B and almost halved its air consumption in comparison with the KZ03. In addition to improving the stability of pressure control, this also reduces the burden on the environment by saving energy.

With regard to the guide O-ring, we took countermeasures for potential problems such as sliding friction and hardening under low temperatures to improve the reliability of long-term operation.

As a means of smoothing the surface of the valve without using electrolytic polishing, we adopted a roller burnishing process that produces an effectively smooth surface while minimizing environmental impact.

The volume of the RA1B is approximately 70 % smaller than that of the KZ03. Although a smaller size is disadvantageous in terms of flow characteristics, the suction tube structure and other features enable us to meet the performance specifications. When determining the features of the suction tube, we were able to significantly reduce the man-hours required by linking the evaluation testing and fluid analysis and devising efficient methods of analysis.

Moreover, thanks to the compact size of the product and inventive manufacturing, the cost of model RA1B has been maintained at almost the same level as that of the KZ03 despite an increase in the number of parts.

6. Conclusion

The RA1B pressure regulator with filter was developed as the successor to model KZ03 and has achieved the targeted compactness and environmentally friendly design while improving the stability of pressure control.

Our hope is that this unit will contribute to the miniaturization, high efficiency, and long-term reliability demanded in recent years for field equipment that incorporates pressure regulators.

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