Development of New Smart Valve Positioners for Enhanced Safety of Plant Operations

Minoru Fukuda
Advanced Automation Company
Azbil Corporation

Kouji Okuda
Advanced Automation Company
Azbil Corporation

Yohsuke Inagaki
Advanced Automation Company
Azbil Corporation

Takashi Nomiyama
Advanced Automation Company
Azbil Corporation

Naoyuki Aota
Technology Development Headquarters
Azbil Corporation

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The new 700 series of industrial valve positioners has been developed based on the 300 series, which has been receiving good reviews. While retaining core components of the earlier positioners, the 700 series offers more robust control features and valve diagnostic functions, simple adjustment and setup, as well as a liquid crystal display and operation buttons. It complies with the latest communications standards given in international specifications. In combination with our PLUG-IN Valstaff control valve maintenance support system, the 700 series achieves a high level of optimization and efficiency for maintenance timing. Together they are utilized for early detection of abnormal tendencies by online diagnosis and for judging whether overhaul is necessary during regular maintenance.

1. Introduction

Along with recently increasing demand for highly safe plant operation, there is a renewed appreciation of the importance of control valves, because they directly control process fluid, and valve errors have a very large impact on plant operation. At the same time, demand for cost reduction with regard to maintenance performed to avoid control valve errors has also increased. Generally, control valve maintenance is done periodically. Because the pressure, temperature, and other characteristics of fluid vary, it is difficult to standardize maintenance methods. Thus, to prevent errors during operation, the tendency is to err on the side of caution with regard to maintenance frequency. Recently, however, control valves are being fitted with smart positioners to control them. Such positioners have built-in diagnostic functionality, making it possible to find control valve errors at an early stage and to estimate the optimal timing for maintenance, contributing to safe plant operation as well as the streamlining and standardization of maintenance.

We have recently developed the 700 series, a new model that is the successor to our 300 series smart valve positioner, of which more than 500,000 units have been shipped. The new 700 series inherits the time-proven core components of the 300 series, has enhanced control characteristics and control valve diagnostic functionality, and is equipped with a liquid crystal display (LCD) and operation buttons that facilitate adjustment and setup.

2. Overview of valve positioners

The valve positioner is a controller that detects the position of the control valve stem, compares it with the position that the operation signal is specifying, and controls the air pressure signal to the actuator so that the actual position is correct. A block diagram for the positioner is shown in Figure 1.

The operation signal used for positioners has been changing from air pressure (20–100 kPa) to electrical current (4–20 mA), and digital fieldbus signals are also being used. Smart positioners with a built-in microprocessor have recently become predominant as a result of this transition. Smart positioners have a higher control performance than conventional mechanical positioners and can be equipped with a variety of smart functions such as automatic setup and control valve diagnostics. With these built-in smart functions, the 300 series, launched in 1998, was well received by a wide range of users not only in the oil, petrochemical, and chemical plant markets, but also in the markets for iron and steel, paper and pulp, food, pharmaceuticals, and others. The 300 series has shipped a total of more than 500,000 units.

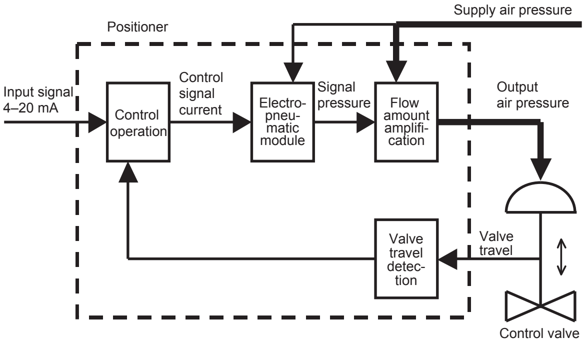

Figure 1. Block Diagram for a Valve Positioner

The 700 series was developed to not only enhance control valve diagnostic functionality but also to further extend the features of the conventional 300 series to improve customer value in the field. This series has the following enhancements.

- Control valve diagnosis: There is a built-in pressure sensor, and diagnostic functions for cutoff errors, actuator errors, and friction errors have been enhanced.
- Field operation: The local user interface (LUI) makes adjustment and setup easy.
- Auto setup (automatic adjustment function): Setup is 30% faster than the 300 series.
- Support for a wide range of specifications in one unit. The built-in double-acting pilot relay works with both single-acting and double-acting actuators.
- Energy efficiency: Air consumption is 20% less than the 300 series.
- Controllability: The double-acting actuator is 20% faster than that of the 300 series.

The 700 series smart valve positioner is shown in Photograph 1.

Photograph 1. 700 Series Smart Valve Positioner

3. Software and diagnostic and monitoring functions

3.1 Software framework

This section describes key features of the 700 series software. Since 700 series positioners operate as 4–20 mA devices, the clock speed must be reduced to lower the current consumption of the microprocessor. On the other hand, the total amount of processing by the software has rapidly increased in proportion to the enhancements made to diagnostics, status monitoring, main unit setup, and other functionality. Innovations were therefore required with regard to the software. In addition, as the scale of software development has increased and become more complicated in line with this increase of functionality, in order to achieve high quality, an objective was set for the realization of a high degree of design freedom, the facilitation of change, and maintainability through a modular structure.

3.1.1 Implementation of a two-level framework

With the evolution of microprocessors, it has become feasible to adopt a real-time operating system (RTOS) in field devices that operate constantly and require low current consumption (a low clock speed). Therefore, we have adopted an RTOS in the 700 series. The use of an RTOS and modular software framework improves design flexibility and facilitates functional enhancement.

However, previous attempts to control valves using an RTOS led to performance problems such as slowed response time due to RTOS overhead becoming a bottleneck. Because continuous valve control requires time-critical processing, any delay immediately leads to a deterioration in control performance.

Therefore, we divided the tasks that the valve positioner must perform into those that must be processed on the order of 10 ms and those that can be processed more slowly. We then designed a two-level execution control system that executes the first type of tasks using interrupts outside RTOS control (fixed-cycle timer interrupt) and executes the second type under RTOS control (as tasks), as seen in Figure 2.

With this framework, we separated time-critical functions from the RTOS, eliminated the negative effects of the RTOS in terms of performance and quality, and facilitated the addition and modification of valve diagnostics and other such added value at the same time.

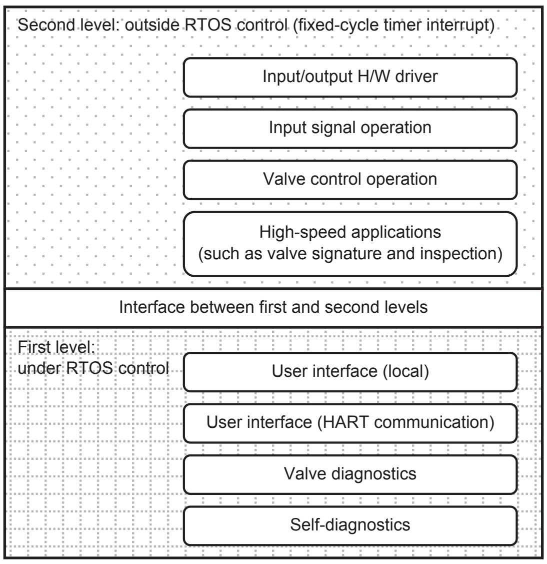

Figure 2. Division of Execution Control Systems and Functions

3.1.2 Reducing software processing and stabilizing the control period using direct memory access

Time-critical processing such as input/output hardware control or valve control operation is executed by interrupts, outside of RTOS control. We implemented a pressure sensor for this series to enhance diagnostics. This caused an increase in analog input, which increased the amount of processing for input/output hardware control and input signal operations. At the same time, we needed to significantly shorten the valve control cycle in order to achieve control that leverages the high-gain pilot relay described below. To meet this demand, the 700 series employs direct memory access (DMA) for input/output hardware control. In this system, data to be transmitted are automatically transferred to the serial communication transmission data register, and output port data are automatically transferred to the output port data register by DMA using a fixed-cycle timer interrupt (which is outside of RTOS control) as a trigger, which means that most direct interaction with external hardware is completed without being mediated by software. As a result, the software merely has to rewrite transfer data by the time the next timer interrupt occurs, causing hardware control-related software processing to be significantly reduced.

A stable input/output cycle for valve control is desirable as variations in cycle lead to unstable control. Therefore, in an ideal design, the maximum priority possible should be given to this processing so that it will not be delayed due to other processing if software controls the input/output hardware. However, currently positioners do not simply control valves. They play an increasingly important role as information devices that constantly transmit the current valve travel and other process statuses, as well as the valve status as found by the diagnostics. Therefore, host communications functionality is also important. With regard to communication, compliance with communication standards is as important as high reliability. HART communication is an important standard communication protocol in the industrial measurement and control field. In HART communications, there are strict rules about the gap time between bytes in incoming frames. To satisfy this requirement, the positioner must receive data on a byte-by-byte basis at the maximum priority. If we had implemented input/output hardware control as software processing, the input/output timing would have been delayed by this per-byte processing, causing the control cycle to be unstable during the receiving of HART data. The resulting control instability would probably have been unavoidable. Using DMA completely eliminated this problem.

3.2 Auto-setup function

The valve auto-setup function, a world-first that was built into the 300 series, has contributed to the reduction of work hours and the improvement of efficiency in the field with its ease of use. In the 700 series, important features that affect the performance of diagnostics have been added to this auto-setup functionality. These new features make setup still faster and allow the collection of initial diagnostic information.

Full stroke valve operations account for most of the auto-setup time. The number of such full stroke operations, which were performed three times in the 300 series, was reduced to two times in the 700 series by storing all valve positions and elapsed time during full stroke operation in large-capacity memory and then referring to the stored information later (this feature is patent-pending).

The initial diagnostic information necessary for valve diagnostics can be acquired with high accuracy through the performance of a dedicated operation. Such an operation is not difficult to implement. The initial information includes the relationship between the output pressure and the valve travel, valve friction, and the relationship between control output and output pressure. This information can be easily obtained by, for example, slowly moving the control output back and forth between 0% and 100%. However, this method requires one full stroke, which is the amount of reduction that we achieved for this new series, which would make it impossible to reduce the overall time required.

We designed and implemented a valve operation method to extract each type of information at a necessary and sufficient level of accuracy in order that both the determination of control parameters and the acquisition of initial diagnostics information can be completed as quickly as possible during auto-setup. The designed valve operation consists of reciprocating micro ramp (inclination) operations at two intermediate travel points (Figure 3). The reciprocating micro ramp with optimized width and speed allows the measurement of quasi-static statuses (control output, back pressure of nozzle, output pressure, and travel) around the operating position. This operation is performed at two points and initial diagnostics information is calculated from measurement results and used for diagnostics (this feature is patent-pending).

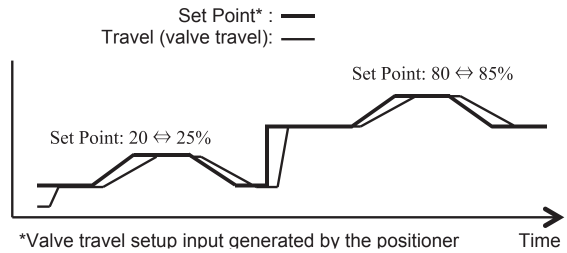

Figure 3. Reciprocating Micro Ramp Operations at Two Intermediate Travel Points

3.3 Diagnostic functions

3.3.1 Control valve maintenance

Because the control valve directly controls fluid through its operation, an error of a control valve can even affect plant control and operations. Appropriate maintenance, therefore, is required to prevent errors in order to allow safe and stable plant operation. To be able to deal with increased maintenance work with limited maintenance budget or staff, maintenance needs to become more efficient and optimized.

The objective behind the diagnostic functions of the 700 series is not only the monitoring of control valve status and the detection of a tendency towards errors or unstable operation at an early stage (predictive maintenance) so as to contribute to stable operation. Another objective is to facilitate the transition from time-based maintenance (TBM) to condition-based maintenance (CBM) in order to achieve greater efficiency. In addition, a function that inspects control valve motion allows for the standardization of inspections and enables maintenance personnel to pass on their maintenance techniques.

3.3.2 Features of 700 series diagnostic functionality

The 300 series calculated a variety of diagnostic indices to detect tendencies for error or deterioration in a control valve based on valve travel data. In combination with PLUG-IN Valstaff (described below), this series has shown successful results for maintenance of control valves and has been well received. The 700 series has a new built-in pressure sensor to monitor the supply air pressure, nozzle back pressure, and output air pressure from the positioner. This allows for further improvement of the diagnostic functions by adding new diagnostic indices that use these values.

As shown below, the diagnostic items are broken down into online diagnostics (diagnostics that can be performed during operation) and a variety of items checked during offline diagnosis.

- Control valve error diagnostics (online)
  Direct detection of abnormal phenomena in the control valve
- Control valve tendency diagnostics (online)
  Prediction of trends toward abnormality or deterioration in the control valve based on related statuses
- Positioner diagnostics (online)
  Detection of abnormality in the valve positioner
- Motion inspection (offline)
  Diagnostic movement of the control valve while operation is stopped

As shown above, many online checks were added to the diagnostic functions. The purpose of these additions was to detect errors online at an early stage. Needless to say, there is also value in detecting problems during offline inspection, but with early online detection, stable operation can be achieved through predictive maintenance, and maintenance efficiency can be improved through CBM. For example, by making use of diagnostic data collected until immediately before regular maintenance begins, the regular maintenance time can be shortened by narrowing down the list of control valves that need overhaul.

3.3.3 Details of diagnostic functions

This section describes selected diagnostic functions.

(1) Monitoring of output air pressure validity and maximum friction

During a valve signature inspection, the positioner input signal is ramped between fully closed and fully open status in the offline mode and diagnostic tests are done based on the relationship between the output air pressure and valve travel at that time. Similar data is acquired online during monitoring of output air pressure validity and maximum friction. However, to eliminate effects of the fact that there is some delay between the pressure and valve travel, as well as overshoot and other factors, only pressure and valve travel data that undergoes little change per unit time is used, and static characteristics are acquired. From the acquired pressure data, the maximum (P_O max) and minimum (P_O min) pressures are retained for the travel in increments of 5%.

The output air pressure validity is an index value used to evaluate the validity of the output air pressure of the positioner based on the power balance between the actuator power, the friction mainly on the gland packing, and the reactive fluid force.

The relationship between the pressure and the travel measured at auto-setup is used as a baseline. If the amount of shift for P_O max or P_O min exceeds a threshold value, an alarm is issued. This index value allows the detection of actuator problems (such as the deterioration or inclination of the spring or breakage or hardening of the diaphragm), cutoff errors, and other errors. Figure 4 shows data indicating inclination of the spring in an actuator.

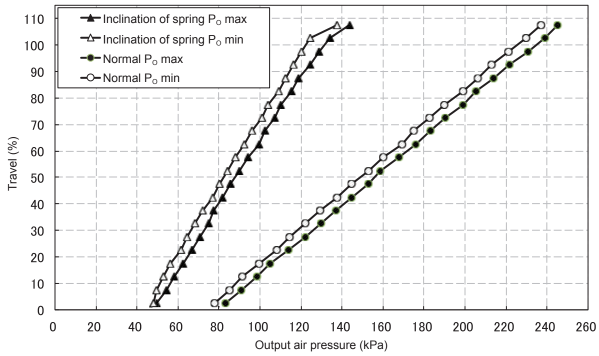

Figure 4. Inclination of Spring in the Actuator

Data captured online indicating a change in the output air pressure and valve travel characteristics can be confirmed.

The maximum friction is calculated as half of the difference between P_O max and P_O min. If the maximum friction exceeds a threshold value, an alarm is issued. This index value can be used to estimate gland packing errors (deterioration, hardening, and softening), cutoff errors, and other problems (Figure 5).

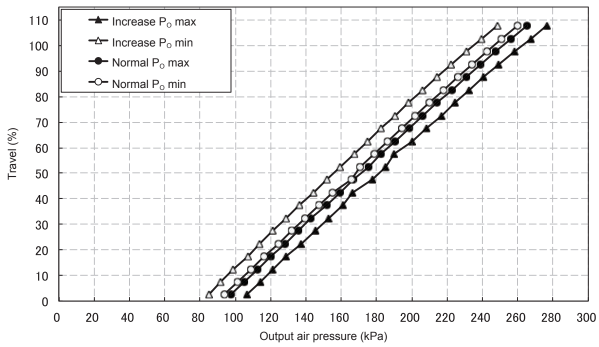

Figure 5. Change when Friction Increases

(2) Positioner air circuit diagnostics

Diagnosis of the positioner air circuits is based on a concept similar to that of the above-mentioned diagnostic index, in that only data exhibiting little change per unit time are employed from the electro-pneumatic module (EPM) drive signal input in the EPM and the nozzle output back pressure from the module, and static characteristics are acquired online. If the amount that these values shift (Drive Sig Max Shift+, Drive Sig Max Shift−) from the baseline measured in auto-setup exceeds a threshold value, an alarm is issued.

Figure 6 shows data indicating clogging of the restriction and nozzle flapper in the positioner. If the restriction located before the EPM is clogged, it becomes difficult to apply output air pressure. This means that a larger EPM drive signal is required, causing Drive Sig Max Shift+ to increase. If the nozzle flapper is clogged, output rises. Therefore, a smaller EPM drive signal becomes sufficient, causing Drive Sig Max Shift− to decrease.

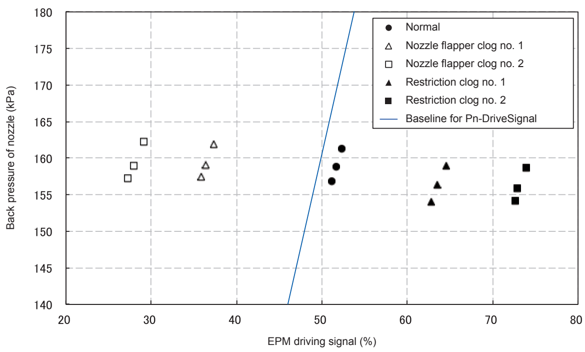

Figure 6. Change when Restriction or Nozzle Flapper is Clogged

(3) Stick-slip

Although the discussion so far has described new diagnostic indices that leverage the new pressure sensor, several algorithms for diagnostic indices that were already included in the 300 series have also been improved. This section describes improvements to the stick-slip index.

The stick-slip index quantitatively detects the occurrence of stick-slip, which is a sign of sticking or galling in the gland, plug seat, or other sections of the control valve.

With a conventional stick-slip index, stick-slip was confirmed if the ratio of the square of the average valve stem speed (X) and its mean square (Y) "Y/X" exceeded a threshold value. However, it was found that the index value Y/X may exceed the threshold value in some cases, especially in small control valves, after the input signal becomes a stepped one even though stick-slip does not actually occur. Therefore, we improved the algorithm to calculate Y/X for the input signal in the same way and evaluate stick-slip only when the input signal is not stepped (Y/X for the input signal does not exceed the threshold value). This improvement allows for more reliable diagnosis.

(4) PLUG-IN Valstaff

The diagnostic and test functions in the 700 series can be used to maximum effect when combined with PLUG-IN Valstaff, a control valve maintenance support system. PLUG-IN Valstaff operates on InnovativeField Organizer, our device management system (Figure 7), or on Plant Resource Manager (PRM), an integrated device control package from Yokogawa Electric Corporation, and can collect diagnostic data or carry out motion inspections from the valve positioner. PLUG-IN Valstaff can be used to detect error tendencies at an early stage and to determine whether an overhaul is required during regular maintenance, and helps optimize the timing of maintenance and make it more efficient by displaying an online diagnostic data history and by producing a variety of reports.

3.4 Setup and monitoring functions

When developing the 700 series, we included new setup and monitoring functions (using a local user interface: LUI) and simplified device operation and checking. The 300 series facilitated setup with functions such as auto-setup and zero/span adjustment. These features

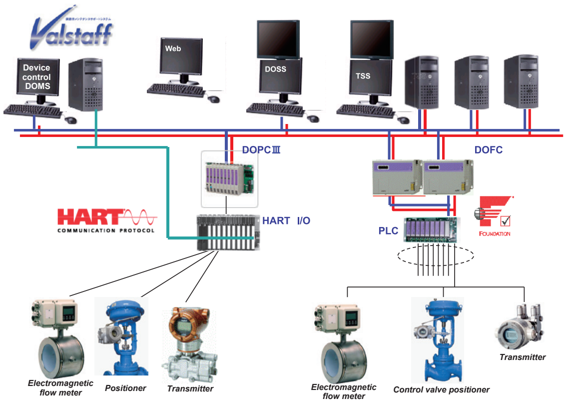

Figure 7. InnovativeField Organizer

provide value by making startup and maintenance in the field more efficient. With its built-in LUI, the 700 series facilitates the detailed adjustment, operation, and testing of valves from the main unit, and makes it easy to check input/output during operation, operation status within the positioner, all pressures in the air circuit and other operation statuses, a variety of settings, including software version, and self-diagnostics status. The LUI includes four push-buttons and an LCD screen. We employed a method of transmitting the switch signals that does not involve contact with the explosion-proof housing using magnets and magnetic sensors so as not to impair the pressure-resistant explosion-proof performance of the housing, which satisfies explosion-proof specifications (this feature is patent pending). This allows for user operation of the device in an explosion-proof atmosphere. Photograph 2 shows the LUI with the main unit cover opened to show the operation buttons.

Photograph 2. Local User Interface

4. New air amplification mechanism (pilot relay)

During the development of the new 700 series, we had three new objectives related to the pilot relay. The first was to enhance control responsiveness to improve the dynamic characteristics of the double-acting actuator controlled by the positioner. The second objective was to increase durability to reduce the frequency of maintenance by customers. The third was to reduce the amount of steadily consumed air to reduce running costs incurred by the customer as well as environmental impact. In addition, we sought a compact framework that would fit in the main unit of the valve positioner.

4.1 Adoption of an integrated layout and molded diaphragm

The conventional 300 series employed an amplification method to drive the reversing relay by using the output pressure P_{O1} of the pilot relay when controlling the double-acting actuator. However, the reversing relay outputs output pressure P_{O2} after receiving P_{O1}. This partly contributes to an increase in wasted time and a larger time constant as well as lower control responsiveness. To improve the controllability for the double-acting actuator in this context, we followed the integrated structure used in old mechanical valve positioners, where two output pressure chambers are diagonally located, whose supply and exhaust ports are alternately opened and closed. Figure 8 illustrates this structure.

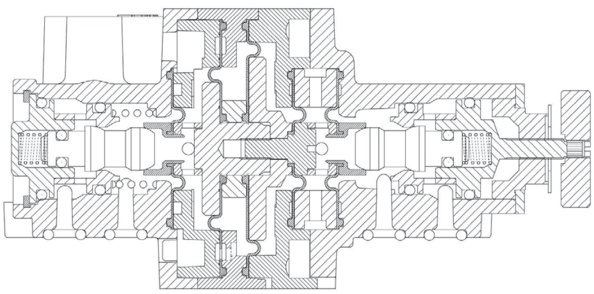

Figure 8. Integrated Pilot Relay

While the conventional pilot relay was located outside the positioner, the new pilot relay is housed in the housing. Therefore, a reduction of its size was an inescapable requirement. It was necessary to minimize the capacity of the signal air chamber that receives the air pressure signal (nozzle back pressure: P_N) from the electro-pneumatic module and lower the rigidity of the diaphragm to facilitate movement in order to further improve responsiveness. To meet these challenges, we reduced the span using a Bellofram molded diaphragm (Figure 9).

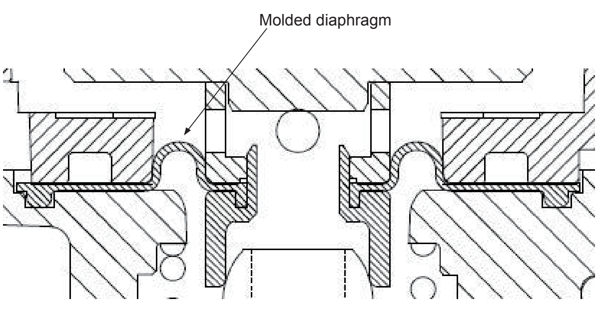

Figure 9. Bellofram Molded Diaphragm

The conventional integrated pilot relay partitioned the output air pressure P_{O2} chamber and nozzle back pressure P_N chamber, located side by side, by using an O-ring. However, this structure inverts pressure and lowers durability. To avoid these problems, an exhaust chamber is located between the air chambers and the diaphragm is used to partition the air chambers rather than the O-ring to ensure higher durability in the new pilot relay (patent pending). Adopting a molded diaphragm reduces the pressure receiving area as compared with a conventional flat diaphragm. Since the applied power is lower, durability is expected to improve dramatically.

For positioners that use the nozzle flapper mechanism, durability deterioration due to a clogged nozzle is a problem. We therefore employed a design with a high static gain (relationship between P_{O1} and P_N) for the pilot relay to ensure a margin for clogging to make a clogged nozzle less likely.

4.2 Integrated layout with high gain

A framework comprising double-acting components with an integrated layout was generally used in old mechanical valve positioners. However, to increase the change (gain: G) of P_{O1} for P_N, it is necessary to make the pressure receiving area for P_N, A_N, larger than the pressure receiving area for P_{O1}, A_{O1} (Formula 1).

$$G=A_N/A_{O1} \qquad (1)$$

However, increasing A_N increases the capacity of the signal air chamber, which leads to lower controllability. Although a structure using an O-ring was adopted as a measure to reduce the pressure receiving area for P_{O1}, durability was a problem, as described above. The way these challenges were met is described below.

As P_{O1} is applied to both the exhaust and supply ports, A_{O1} can be expressed with Formula 2.

$$A_{O1}=A_{Oexh}-A_{Osup} \qquad (2)$$

A_{Oexh}: Pressure reception area at the exhaust port side
A_{Osup}: Pressure reception area at the supply port side

To reduce A_{O1}, A_{Oexh} must be reduced. However, there is a lower limit because this value is restricted by the exhaust port diameter and the span of the diaphragm. Therefore, we adopted a structure that reduces the pressure receiving area by increasing A_{Osup}. This allowed us to increase gain while continuing to use an integrated layout. However, if the diameter of the supply port increases, the force applied by the supply air pressure to the bottom of valve stem (P_S) increases, increasing deadband and lowering controllability. To solve this problem, we adopted a structure in which supply air pressure is not applied to the bottom of the valve stem (P_S cancellation structure; this feature is patent-pending). This is shown in Figure 10.

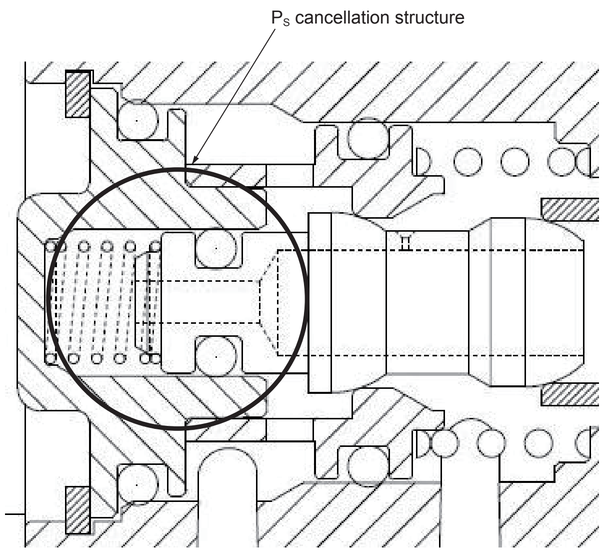

Figure 10. Supply Air Pressure Cancellation Structure

4.3 Structure for reducing air consumption

The bleed hole in the pilot relay, which vents excess air, improves stabilization from the exhaust mode to the supply mode when P_{O1} is bled. This hole also improves stabilization from the supply mode to the exhaust mode when P_S is bled. That is, there is a trade-off relationship between size reduction of this bleed hole to reduce air consumption and deterioration of controllability. However, the P_S cancellation structure adopted in this series reduces the power applied to the bottom of the valve stem, and therefore can reduce the amount of bleeding corresponding to this reduction. As a result, we were able to produce a pilot relay with low air consumption by leveraging the advantages of P_S cancellation structure to achieve a high gain.

5. Circuit structure

When designing the hardware for the 700 series, we used low current circuit technology, which is a key feature of field devices that must operate at 4 mA to 20 mA, and adopted a shared modular configuration for the circuit block to allow its mutual use with other products. For communication, this series is certified with the latest HART communication standard, HART 7, and the latest Foundation Fieldbus (FF) communication standard, ITK 6.1, applicable to all industrial field devices (as of December 2013).

For modular design, we first targeted the FF and HART communication functions to be shared with our pressure transmitter, electromagnetic flowmeter, and other products and attempted to share them by using the FF communication circuit, FF power supply circuit, and HART communication circuit blocks. In this design, which is specific to this valve positioner, we made a block to which we added a valve control function and HART function to the main circuit block module (Figure 11). In addition, we separated out each additional function that is specific to models in the 700 series into individual modules. Also, we created a valve travel transmission function to monitor the valve travel in a module, allowing it to work alongside the HART communication function, which is something that was impossible in the past. This made it possible to make the main circuit block sharable, to switch the model-specific FF blocks with the valve travel transmission blocks, to select the external input/output circuit block, etc., depending on the model, to decide whether to use the display block, and to create an independent internal air pressure sensing circuit block. By organizing and limiting the functions of each module, the clarification of design assessment was made easier by specifying each function to guarantee design quality. We also made it easy to check and guarantee the quality by clarifying the items for inspection and specifications at the component phase during production, and consequently raised quality.

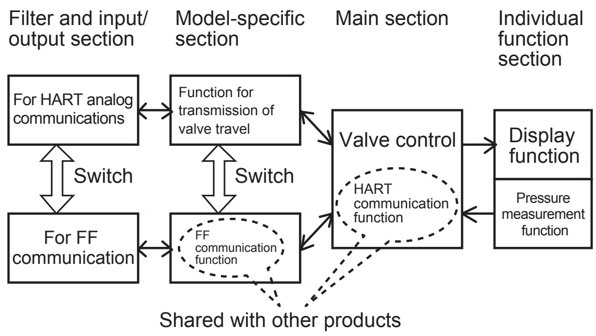

Figure 11. Circuit Block

6. Conclusion

This paper reports on the technological development of the 700 series, a new model that is the successor to our popular 300 series smart valve positioner. The 700 series supports the latest communication standards, has enhanced controllability and performance for its diagnostic functionality, and makes setup and monitoring work in the field more efficient with its LUI, in order to realize safer field operations on customer premises.

References

(1) Toshiharu KAGAWA, Katsuya HONDA, Masashi SHIMIZU: "Analysis of Electro-Pneumatic Positioner Valve System Considering Non-linear Characteristics of Pilot Valve," *Transactions of SICE*, Vol. 29, No.11, 1337/1341 (1993).

(2) Toshinori FUJITA, Toshiharu KAGAWA, Masaaki TAKEUCHI: "Disturbance Characteristics of Control Valve Positioner," *Proceedings of 4th Triennial International Symposium on Fluid Control, Fluid Measurement, and Fluid Visualization*, B, 847/852 (1994).

(3) HONDA et al.: "Element Technologies for Smart Valve Positioner," *Proceedings of 13th Symposium on Fluid Control*, pp. 21–24 (1998).

(4) KASEDA et al.: "Study on Online Diagnostics for Control Valve," *Journal of the Society of Plant Engineers Japan*, Vol. 9, No. 4 (1998).
(5) KASEDA, OTSUKA, NAGASAKA, KAGAWA: "Experimental Study on Operation Characteristics Diagnostics for Air Pressure Control Valve," *Transactions of the Society of Instrument and Control Engineers*, 35, 594/599 (1999).
(6) Masato KURODA, Yohsuke INAGAKI, Masahiro URATA, Toshinori FUJITA, Toshiharu KAGAWA: "Positioning Control Performance of Separate-Type Valve Positioner," *Proceedings of INTERMAC 2001 Joint Technical Conference* (CD-ROM, 2001).
(7) M.Kuroda et al.: "Control Valve Diagnostic Using Fieldbus," *Proceeding of ISA/EXPO 2001 Technical Conference* (2001).
(8) Minoru FUKUDA: "Support System for Optimization and Streamlining of Control Valve Maintenance," *Instrumentation*, Vol. 58, No. 6 (2008).

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Affiliation of Authors

Minoru Fukuda	Marketing Department, Advanced Automation Company
Kouji Okuda	Development Department 2, Advanced Automation Company
Yohsuke Inagaki	Development Department 2, Advanced Automation Company
Takashi Nomiyama	Development Department 2, Advanced Automation Company
Naoyuki Aota	Product Development Department, Technology Development Headquarters