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Development of the Fuel Tank Closed Valve using a stepping motor

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Abstract

With tightening of environmental regulations for gasoline evaporation, closed tank systems are expanding for vehicles with small amount of canister purge volume, such as PHEVs. And a pressure control valve is required to shut off the pressure in these tank systems. In this paper, we introduce the compact and lightweight Fuel Tank Closed Valve used a stepping motor.

1. Introduction

The regulations on evaporative emissions have been further strengthened to prevent air pollution. The vehicle evaporative emission control system works by temporarily collecting gasoline vapor in a canister, purging the absorbed vapor using the negative pressure from the running engine, and combusting the purged vapor. However, in the automobile market, the number of PHEVs, HEVs, and other environmentally friendly vehicles with excellent fuel economy has been increasing. These types of vehicles have difficulty meeting evaporative emission regulations due to the reduced canister purge volumes.

Recently, a closed fuel tank system has been widely adopted as a technology that allows vehicles with reduced purge volumes to meet regulations. The system requires a control valve to regulate tank pressure. This paper introduces the development of a compact and lightweight fuel tank closed valve using a stepping motor.

2. Composition of Closed Fuel Tank System

2.1. Comparison between a conventional system and a closed fuel tank system

First, a conventional system is shown in Figure 1. The gasoline vapor generated in the fuel tank is continuously collected in a canister. The collected vapor is then purged using negative pressure in the intake pipe of a running engine and combusted in the engine.

Next, an example of a closed fuel tank system is shown in Figure 2. In this example, a closed valve is positioned between the fuel tank and the canister, allowing gasoline vapor to be absorbed by the canister only when needed. Additionally, a pressure sensor is installed on the fuel tank to continuously monitor its pressure.

Figure 1 Conventional system

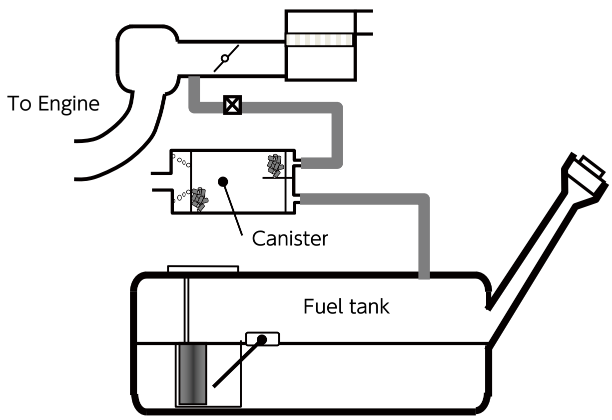
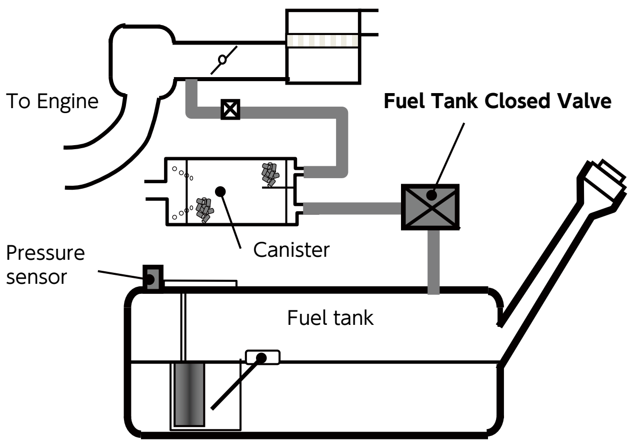


Figure 2 Closed fuel tank system



2.2. Functions of the Closed Valve

A closed valve generally needs to fulfill the three main functions shown in (1) to (3) below. Each of these functions is necessary depending on what the vehicle is doing (e.g., when parked, in operation, or being refueled):

(1) Sealing function (when parked)
(2) Relief function (when parked)
(Protection of the fuel tank with a mechanical relief valve)
(3) Flow rate control function (when in operation and being refueled)

Table 1 shows the required functions based on the situation

Table 1 Required Functions based on the Situation

Situation	Parking	Driving	Refueling
Required function	(1) Seal function (2) Relief function	(3) Flow control function	(3) Flow control function
	Seal up to specified pressure, release pressure if exceeded	Control flow rate according to purge to the purge	Depressurize before refueling, hold fully open to secure flow path

3. Development Concept

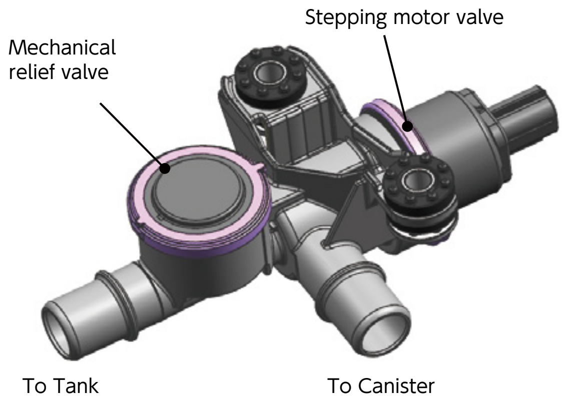
3.1. Overview of the Developed Closed Valve

The closed valve was developed to achieve the sealing and flow rate control functions through the integration of the following measures:

- Adoption of a compact stepping motor
- Stroke control using a feed screw mechanism
- Use of a valve with a two-body structure
- Integration of a mechanical relief valve

Figure 3 shows an overview of the developed closed valve.

Figure 3 Developed Closed Valve



Currently, the solenoid type is the most common type of closed valve that has been commercialized. Table 2 shows a comparison between the closed valve using a stepping motor and a closed valve using a solenoid valve with respect to several specification items.

Table 2 Comparison with the Solenoid Type

Actuator type	Solenoid	Stepping motor
Refueling	△ Valve opening hold requires energization	○ No energization required for valve open holding
Driving	△ Flow control by on-off Must be responsive	○ Flow control by stroke
Response	○	△
Leakage	○	○
Size	△	○
Weight	×	○

The solenoid type excels in responsiveness but tends to have a larger body structure and be heavier to secure a passage for refueling. In contrast, the stepping motor is less responsive than the solenoid type but is capable of stroke control using a feed screw mechanism, which allows the valve to be downsized.

Figure 4 Overview of the Stepping Motor

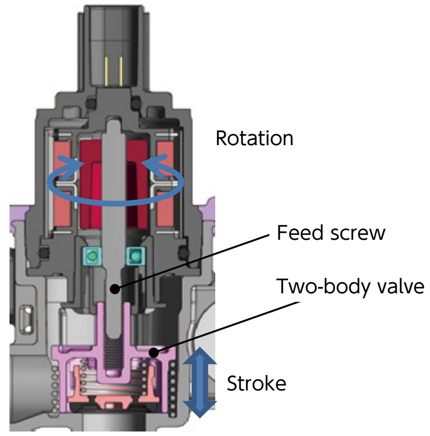


Figure 4 shows an overview of the stepping motor. It can reduce pressure loss when the valve is fully opened for refueling by ensuring a certain stroke amount. Additionally, it can achieve micro flow rate control by reducing the pitch size of the feed screw. Furthermore, reducing the lead angle of the feed screw enables the valve to hold its position against an axial load without energization, thereby reducing power consumption during refueling. Figure 5 shows the relation between friction and lead angles.

Figure 5 Relation Between Friction Angle and Lead Angle

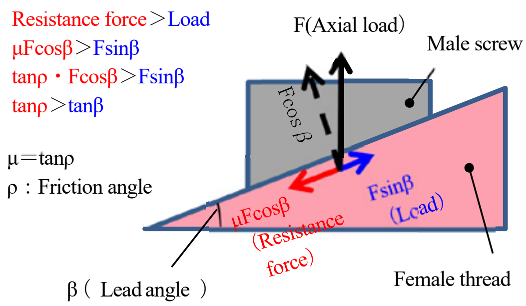
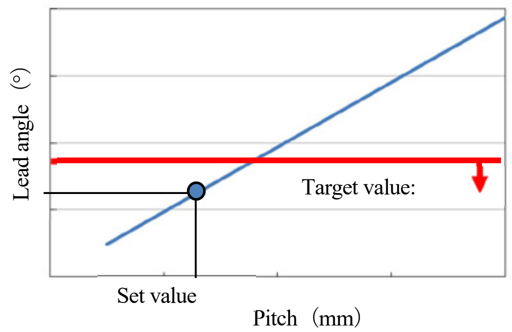


Figure 5 Relation Between Friction Angle and Lead Angle



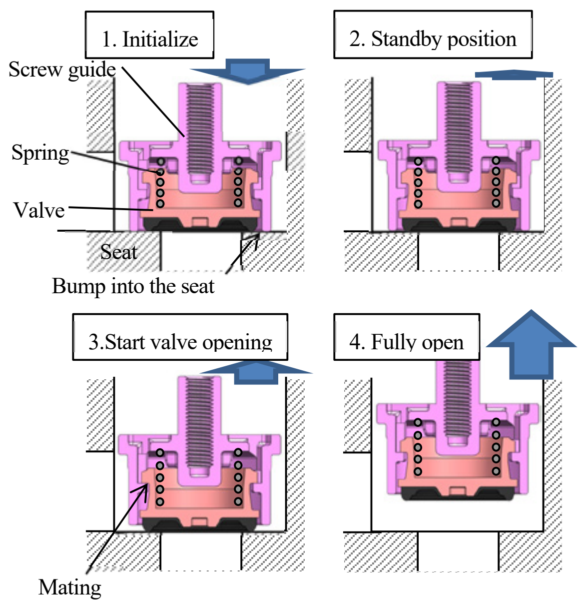
3.2. Valve Structure

The stepping motor is characterized by its ability to control its position based on the number of steps from a control origin, without requiring a sensor to detect the position. Therefore, the stepping motor requires initialization to define the control origin.

Initialization is performed with the valve in contact with the seat, which requires the valve to have a rubber member to achieve the sealing function. This raises a concern that variations in the deformation of the rubber due to fluctuations in motor thrust may prevent the sealing function from being stably maintained. Thus, a valve with a spring-loaded, two-body structure has been adopted to achieve both accurate initialization and a reliable seal.

Figure 6 shows the valve structure. This structure enables the initialization to be stably performed with the edge face of a feed screw guide in contact with the seat. This structure allows the valve to be stored inside the screw guide along with a spring, so that the spring force continuously maintains a stable seal. Both the screw guide and the valve have stops that fit into each other, causing the valve to be separated from the seat by a certain stroke.

Figure 6 Valve Structure

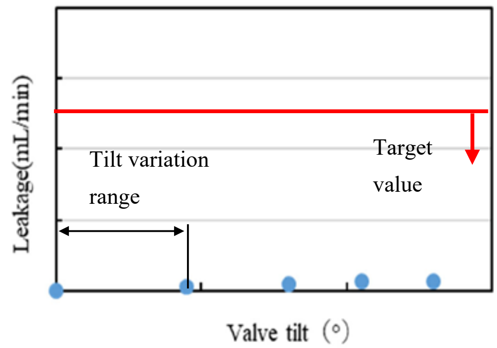


4. Performance of the Developed Closed Valve

4.1. Sealing Performance

The two-body valve structure provides stable sealing performance. This structure allows the valve to remain aligned with the seat, even when the motor and seat are inclined relative to each other. Figure 7 shows the relation between valve inclination and sealing performance.

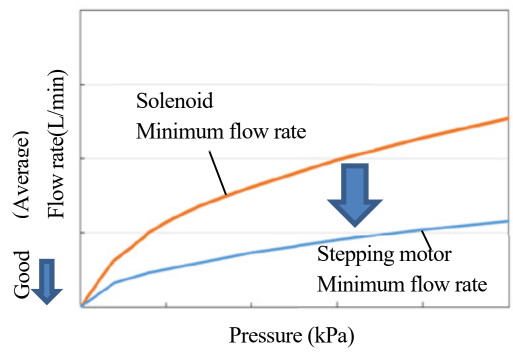
Figure 7 Relation Between Valve Inclination and Sealing Performance



4.2. Micro Flow Rate Control

The developed closed valve uses stroke control, achieved through a combination of a motor and a feed screw, to regulate the micro flow rate. As a result, the stroke control enables a vehicle to release pressure even in a state with minute purge amounts. Figure 8 shows a comparison of flow rate characteristics between a solenoid type and a stepping motor type. The stepping motor type is superior to the solenoid type in terms of micro flow rate control, as the solenoid type requires high responsiveness while maintaining sufficient stroke.

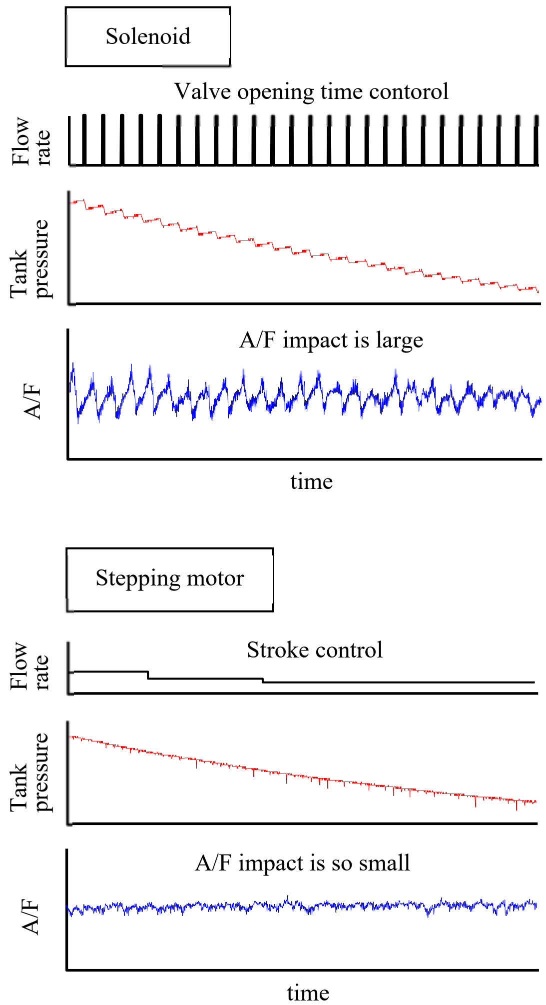
Figure 8 Comparison of Flow Rate Characteristics



4.2. A/F Fluctuation Control

An example of flow rate control while a vehicle is running is the release of pressure from the fuel tank in coordination with purging during engine operation. The solenoid type releases pressure by controlling the valve opening time, which requires a large intermittent flow. This may cause a delay in fuel feedback control, leading to significant A/F fluctuations. In contrast, the stepping motor type releases pressure by controlling the stroke with a small, continuous flow. This allows fuel feedback control to respond to changes in flow rates and helps suppress A/F fluctuations. As a result, the stepping motor type is expected to improve drivability. Figure 9 illustrates the difference in A/F fluctuations based on the control methods.

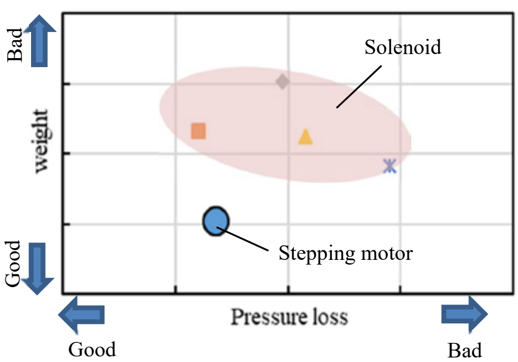
Figure 9 Difference in A/F Fluctuations based on Control Methods



4.3. Achieving Both Low Pressure Loss and Downsizing

Low pressure loss can be achieved by securing the valve stroke. Downsizing can be achieved by adopting a stepping motor, which is over 40% lighter than the conventional solenoid type, contributing to making it the world's lightest closed valve. Figure 10 shows the pressure losses and weights of the two types.

Figure 10 Pressure Losses and Weights



5. Conclusion

A compact and lightweight fuel tank closed valve was successfully developed by using a stepping motor.

(1) A closed valve with a two-body structure was developed to ensure both reliable initialization of the stepping motor and stable sealing performance.

(2) Micro flow rate control based on stroke control contributes to achieving both low pressure loss and downsizing.

Lastly, we express our profound gratitude to all the individuals who supported and cooperated in the development of the fuel tank closed valve.

Reference:

(1) Masanobu Shinagawa, et al., Development of Sealing Valve for Fuel Vapor-containment System, 2006 JSAE Annual Congress (Spring) 20065285

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