

Development of Low-profile Fuel Tank System and Zero Leak Valve for North American Market

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ABSTRACT

In the North American market, the US Honda Odyssey is commonly regarded as the “King of Minivans” because of the great value it provides to customers. Among other things, its low-flat floor packaging offers significant value, and the fuel tank system packaged under the floor greatly contributes to securing sufficient cabin space and making the low floor possible.

For the development of the fourth generation Odyssey, which applies an exclusive platform for the North American market, the underfloor platform was carried over from the previous model. However, the overall fuel tank system design was changed to further improve its reliability and reduce cost.

Specifically, fuel leakage was successfully eliminated by using a 2-vent system located on the top of the tank that consists of a Vent Shut Float (VSF), which detects when the fuel tank is full, and a Rollover Valve (ROV), which allows the tank to vent when the VSF is closed. As a result, the liquid-vapor separation device that was applied to the previous model to address this issue could be removed, thereby simplifying the low-profile tank vent system.

1. Introduction

The fuel line connected to the fuel tank normally consists of two lines: a feed line, which supplies fuel to the engine, and a vent line, which adjusts the tank’s internal pressure by releasing fuel vapor from the tank to a canister. An important function of the fuel tank system is “liquid-vapor separation performance,” which measures the system’s ability to prevent a fuel leak during refueling and maintain an open ventilation passage during various conditions.

To achieve adequate liquid-vapor separation performance, multiple vents may be necessary depending on the fuel tank’s shape. However, based on the vehicle’s inclination, the vents can be submerged in fuel, which can cause fuel to flow out the vent line. Preventing this has traditionally complicated the system. The proposed system and valves discussed in this paper achieve the required performance and simplify the system.

2. Challenges with Prior Design

Generally, fuel tank systems used in Japan and Europe have a rollover valve (ROV) positioned at the top of the tank (Fig. 1) at the location where fuel vapor remains at all times. The ROV position prevents fuel from escaping out the vent line, even when the vehicle is inclined.

During refueling, fuel vapor is released to the atmosphere through a breather tube that is connected to the fuel inlet pipe. When the tank is filled, the breather is submerged, which cuts off the vapor flow to stop refueling.

However, vehicles sold in North America must comply with government regulations that prohibit the release of fuel vapor to the atmosphere during refueling. To comply with this regulation, an On-board Refueling Vapor Recovery (ORVR) system guides the fuel vapor to a canister that adsorbs it during refueling and, when the engine is running, desorbs and releases it to the engine for burning. A vent shut float (VSF), which detects when the fuel tank becomes full, is used to cut off the flow of fuel vapor to automatically stop refueling and to prevent liquid fuel from reaching the canister. Since the VSF also affects the aforementioned liquid-vapor separation performance, just like the ROV,

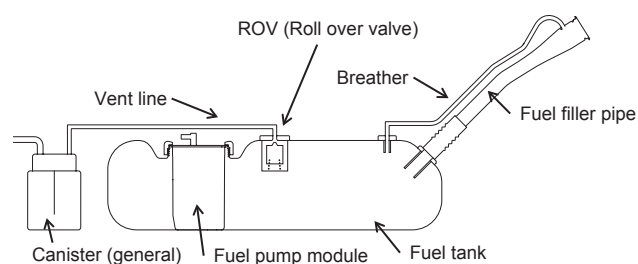


Fig. 1 General fuel system diagram

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normally the VSF is positioned in an area at the top of the fuel tank where only fuel vapor is present.

Other North American regulations that pertain to gases evaporating from a vehicle include the California Air Resource Board's (CARB) Low Emission Vehicle 2 (LEV2) regulation and the Environmental Protection Agency's (EPA) Tier 2 regulation. Both regulations set different conditions, but the LEV2 requirements are stricter and also cover ORVR. Figure 2 shows the conventional LEV2 fuel system.

The "low-flat floor package" in the minivan category makes it difficult to ensure a sufficient fuel tank capacity and an efficient liquid-vapor separation at the same time. A fuel tank with a low-profile (flat) shape must be made larger to accommodate a fuel vapor area where a ROV and a VSF can be installed. However, a larger tank requires more package space, increases weight, adds volume to the vapor area, and ultimately requires a larger canister and higher purge flow rate for the engine to burn the increased amount of vapor. These factors are considerable disadvantages with regards to treating vapors in the fuel tank and improving fuel economy.

To solve these technical challenges, the 2005 model year Odyssey adopted a "2-vent system" (Fig. 3) and a liquid-vapor separation device called a "vent tower" (Fig. 4). The VSF, which is normally positioned at the top of the tank, was moved to a higher location within the vehicle's wheel housing, and the two ROVs were connected to the vent tower by separate lines. This LEV2 system achieved the required liquid-vapor separation performance, enhanced the tank's capacity filling efficiency, and contributed to a low-floor package.

Despite the advantages of the 2-vent system to

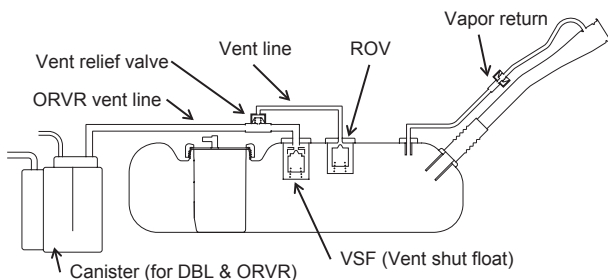


Fig. 2 LEV2 fuel system diagram

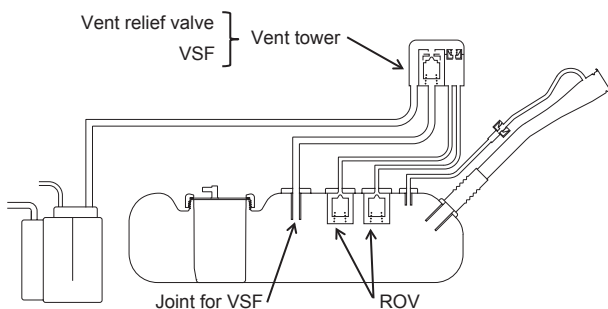


Fig. 3 2005 model year Odyssey fuel system diagram

marketability, compared to a conventional LEV2 system, the positioning of the vent tower still required the following:

- Increased part cost
- Increased package space inside the wheel housing
- Additional tube connections with lines extending from the tank
- Increased fuel permeation amount
- Additional assembly tasks in the manufacturing process
- Protection for the vent tower in the event of a vehicle crash or other dangerous situation

For the 2011 model year Odyssey, the fuel system was redesigned to eliminate the vent tower while maintaining marketability in terms of low floor packaging, fuel tank capacity, and filling efficiency; reduce cost; and enhance reliability.

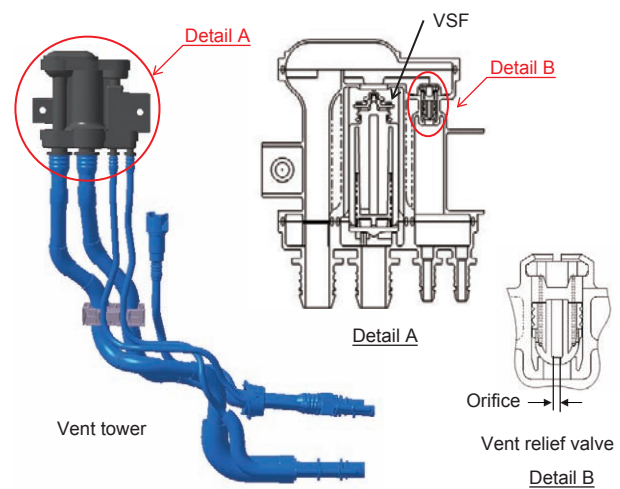


Fig. 4 Vent tower on 2005 model year Odyssey

3. System Concept and Technical Requirements for Components

3.1. System Concept

To achieve the development target, the overall concept of the fuel system had to be clearly defined. This design began with positioning the VSF and ROV on top of the tank, just as a conventional LEV2 tank system.

To ensure the same capacity and filling efficiency of a low-profile tank, a multi-vent system (that is, a system where two or more ROVs are applied) would be adopted as the 2005 model year Odyssey did. However, with the multi-vent system, one of the valves will be submerged when the vehicle is inclined in a certain direction. To meet the required liquid-vapor separation performance, the multi-vent design needs to reliably prevent fuel from leaking out the vent line via the submerged valve.

In other traditional multi-vent systems, a liquid trap is provided in the form of a separator to achieve the required liquid-vapor separation performance. However, such systems require an additional joint between the

vent line and separator as well as measurers to prevent permeation of fuel from the separator itself. This specification could not be adopted since it would be incompatible with the LEV2 regulation. Consequently, a new zero-leak VSF and ROV technology was needed to keep the amount of fuel leak to zero without adding a separator.

Generally, in multi-vent systems, the greater the number of vents, the smaller the required vapor volume, hence a 3-vent system is better than a 2-vent system. However, additional vents require more ROV welding locations on the tank and longer tubes for the vent line, both of which are negative factors since they affect cost, fuel permeation amount, and reliability. To minimize these factors, the “2-vent system with zero-leak valves” concept has only two valves, one ROV and a VSF that also provides the ROV function. Furthermore, a relief valve with an orifice was set at the joint between the vent line on the VSF side and the vent line on the ROV side. As shown in Fig. 5, all of these parts are installed to the fuel tank as one assembly.

3.2. Technical Requirements for Components

After defining the system concept, the specific performance requirements for each system component had to be clearly defined.

3.2.1. VSF

- (1) General performance of the VSF shall be ensured, while keeping the level of leak to zero, using a traditional, anti-stick type multi-stage float.
- (2) One valve shall provide both the “full-tank detection” function and “ROV” function to create a 2-vent system.
- (3) An orifice shall be provided to control the pressure inside the tank when the vehicle is inclined, which actuates the ROV near full-tank capacity.
- (4) The orifice shall control vapor inside the tank in such a way that sufficient auto-refueling stop performance is ensured and the amount of fuel that can be added after auto-stop is kept low. In doing so, the required total P-Q (pressure versus flow rate) characteristics of the entire system shall be satisfied by a combination of this orifice and the orifice in the vent relief valve, which is explained later.

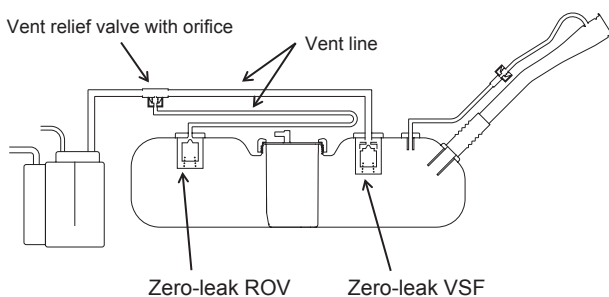


Fig. 5 Concept for 2-vent system with zero-leak valves

3.2.2. ROV

General performance of the ROV shall be ensured, while keeping the level of leak to zero.

3.2.3. Vent relief valve

- (1) The pressure inside the fuel tank shall be adjusted properly through the vent line on the ROV side when the VSF is submerged and flow of vapor is cut off due to inclination of the vehicle.
- (2) The amount of vapor flow shall be adjusted so that when the specified fuel level is reached during refueling, the VSF will actuate to cut off the vapor passage and thereby cause refueling to stop automatically.
- (3) When combined with the VSF orifice, the valve must keep the amount of fuel that can be added after auto-stop low and to a level at which the full-tank level can be maintained.
- (4) When combined with the VSF orifice, the valve shall achieve an appropriate flow of vapor to prevent spit-back of fuel upon auto refueling stop.

3.2.4. Fuel tank

- (1) The structure shall be such that the above valves are retained on the fuel tank.
- (2) The nominal capacity shall be ensured and equivalent filling efficiency achieved based on the same package space as on the previous model.

As listed above, the system concept and technical requirements for each component were clarified before the start of development.

4. Key Technologies

4.1. Zero-leak VSF Construction

Honda's traditional VSF adopts a 2-stage float and its valve re-opening pressure is designed to prevent the valve from sticking when a high volume of vapor is generated in the tank. Traditionally, a large diameter seal is achieved by contact between plastic and rubber, whereas a small diameter seal is achieved between plastic and plastic. However, the small diameter seal design has been associated with a small leak due to either fuel sloshing inside the tank or the seal remaining submerged in fuel for a long period. Therefore, the new design had to eliminate this leak.

If the sealing effect is lost, a leak will occur if the vehicle is inclined and the valve is submerged in fuel. Although this does not pose a concern in a normal system where the VSF is positioned in a vapor area, it did pose a significant challenge in designing the new system. For the new system, the zero-level leak requirement must be 1 ml or less over 1000 hours when the sealed area of the valve is submerged in fuel. Figure 6 shows a structural diagram of the zero-leak VSF.

Furthermore, actuation of the float to provide sealing is based on the reactive force of a spring and buoyancy of fuel, so sealing performance may be lost due to fuel sloshing.

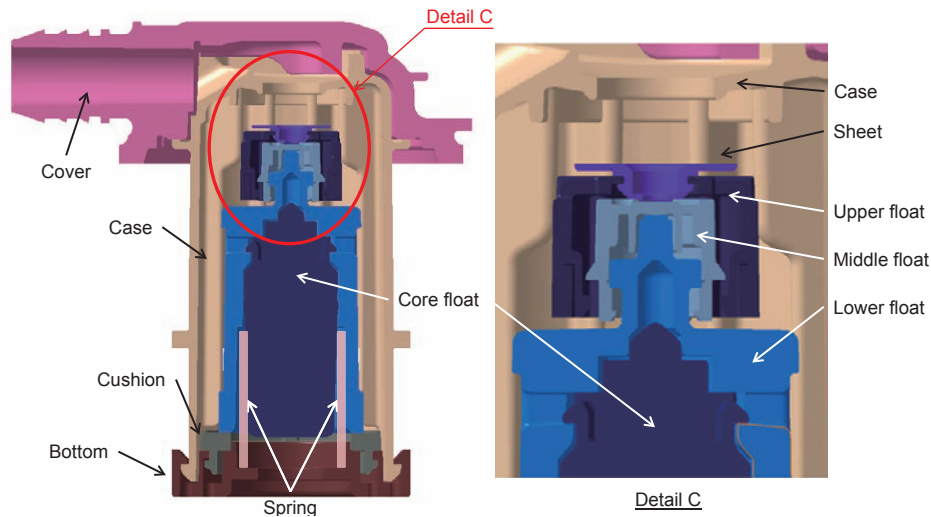


Fig. 6 Zero-leak VSF construction

During development, it was discovered that the conditions most susceptible to leak occurred from vehicle vibration input. Accordingly, an allowable amount of leak was set for each vehicle vibration condition that could occur with the vehicle traveling while the float is submerged. The hardware specifications were set to meet these target values.

The new adopted structure incorporates the following setting to prevent fuel leak, achieve an appropriate seal compression margin, and to ensure sufficient seal performance in a low-temperature environment:

- Seal structure based on plastic and rubber in the small-diameter area
- FKM Sifel material used for the seal rubber
- Adoption of a 3-stage float structure and setting of an auto-pivoting adjustment mechanism capable of absorbing angle variation
- Addition of a float stroke stopper for the small-diameter area

Furthermore, the following changes were made to suppress the effect of an external force to buoyancy behavior and to ensure sufficient sealing performance under vibration and in a submerged state:

- Setting of a core float to reduce the influence of the air volume trapped inside the lower float
- Adoption of POM for the lower float and lightweight PA12 for the core float to reduce the effect of the float's weight
- Increase of the stroke margin in each of the three float stages compared to the traditional structure to improve the valve's ability to remain closed when the lower float drops due to vibration

These design measures allowed us to achieve the zero-leak target value.

4.2. Zero-leak VSF Auto-stop Function

The VSF automatically stops refueling in one of two ways.

4.2.1. Float buoyancy method

As shown in Fig. 7, as the fuel level rises, the float rises and cuts off the flow of vapor and refueling stops.

4.2.2. Breather-type method

As shown in Fig. 8, as the fuel level rises, the vent holes in the VSF case are submerged, the vapor route is cut off, and refueling stops. This cutoff of vapor flow by the actuation of the float occurs secondarily.

The VSF of this system adopted the breather-type level detection method to achieve “full-tank detection” and “ROV” functions with a single valve.

In this system, vapor flow must be shut off in the tank when the full-tank level is detected. However, with the 2-vent system, vapor flow must be permitted when the ROV is inclined and submerged in fuel.

Accordingly, an orifice was integrated in the VSF case to permit vapor to flow to the vapor line even when the vehicle is inclined near its full-tank

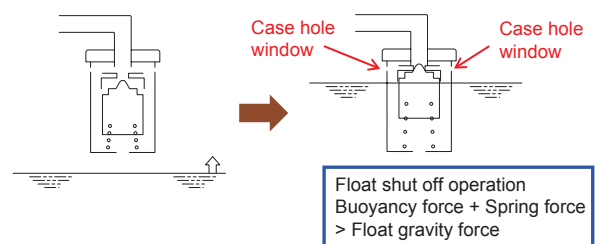


Fig. 7 Float buoyancy type VSF operation mechanism

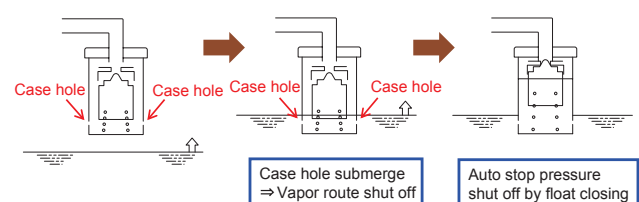


Fig. 8 Breather-type VSF operation mechanism

capacity. When setting the orifice diameter, the “total P-Q characteristics” of the entire system must be investigated, the details of which are explained later.

4.3. VSF Marketability Requirement

When the VSF was installed on the redesigned tank, actuation noise from the plastic of the float contacting the plastic of the bottom plate permeated into the cabin. This had not occurred on the previous model or any other model that used the traditional VSF design. To resolve this issue, an impact-absorbing rubber cushion was added to the bottom plate of the VSF.

4.4. Zero-leak ROV

The traditional seal structure of the ROV was based on contact of “plastic” and “plastic.” As a result, a small amount of fuel leak occurred due to sloshing of fuel inside the fuel tank or the seal remaining submerged in fuel for a long period, just as the small-diameter seal area of the VSF. Accordingly, the new design had to eliminate this leak.

To achieve sealing, the ROV, like the VSF, is structured so that the float is actuated by a force resulting from the reactive force of a spring and buoyancy of fuel. However, the ROV does not have a full-tank detection function, so a one-stage float is applied. The same leak requirement value applied to the VSF was adopted and hardware specifications were investigated to satisfy these requirements.

Figure 9 shows a structural diagram of the zero-leak ROV. This ROV adopts the float buoyancy method.

The newly adopted structure incorporates the following setting to prevent fuel leak, achieve an appropriate seal compression margin, and ensure sufficient seal performance in a low-temperature environment:

- Seal structure based on “plastic” and “rubber” in the seal area
- FKM Sifel material used for the seal rubber
- Ensuring sufficient seal compression margin through a structure that holds the outer periphery of the rubber all

round and causes the rubber to deflect toward the inner periphery side

- Addition of a float stroke stopper

Furthermore, the following changes were made to suppress the effect of an external force to buoyancy behavior and to ensure sufficient sealing performance under vibration and in a submerged state:

- Setting of a core float to reduce the influence of the air volume trapped inside the float
- Adoption of POM for the float and lightweight PA12 for the core float to reduce the effect of the float’s weight

These design measures allowed us to achieve the zero-leak target value.

4.5. Vent Relief Valve

A relief valve with orifice was set at the joint between the vent line on the VSF side and the vent line on the ROV side. This valve controls the flow rate on the ROV side. A structural diagram is shown in Fig. 10.

The valve seal diameter was increased from the conventional structure to ensure the required P-Q characteristics. Furthermore, to stabilize the accuracy of parts, a laser welding method was adopted instead of conventional vibration welding, and the valve was welded after the assembly.

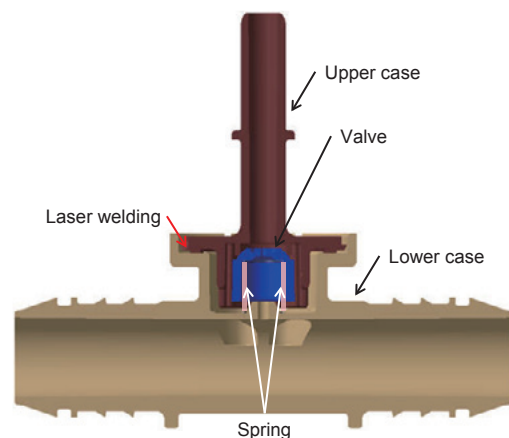


Fig. 10 Vent relief valve for zero-leak 2-vent system

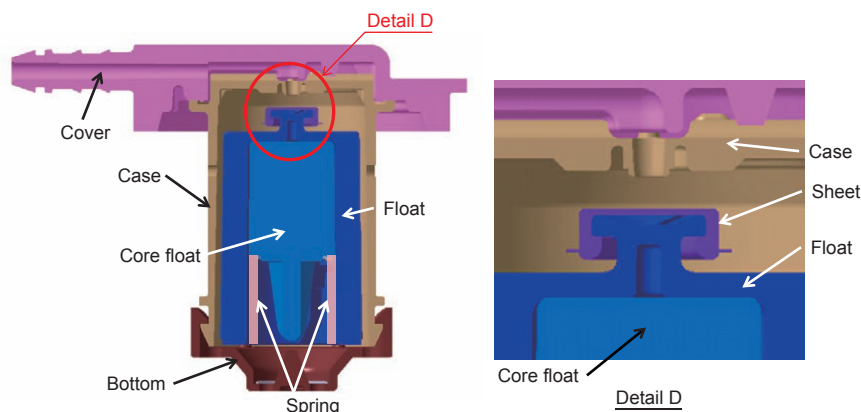


Fig. 9 Zero-leak ROV construction

4.6. Fuel Tank

For the 2011 model year Odyssey, a new low-profile plastic fuel tank that allows for a low-floor package was designed. The tank capacity is 21 gal. (79.5 L) that achieves an 84% capacity filling efficiency.

Figure 11 shows the tank's liquid-vapor separation performance.

As shown in Fig. 12, the valves constituting the vent system are positioned on top of the tank along with their respective vent lines.

Although the general outline of the fuel tank has a profile similar to that of the previous model, the upper and lower halves are welded at three Stand Off locations to ensure sufficient unit strength against the internal pressure of the tank. To most effectively suppress the deforming impact of vacuum on the plastic fuel tank, the welds are located near the three tank bands that hold the tank to the vehicle body. This design minimizes tank vibration bounce that occurs upon deflection by vacuum during engine purge and is effective in minimizing the inputs received by the valves on the tank.

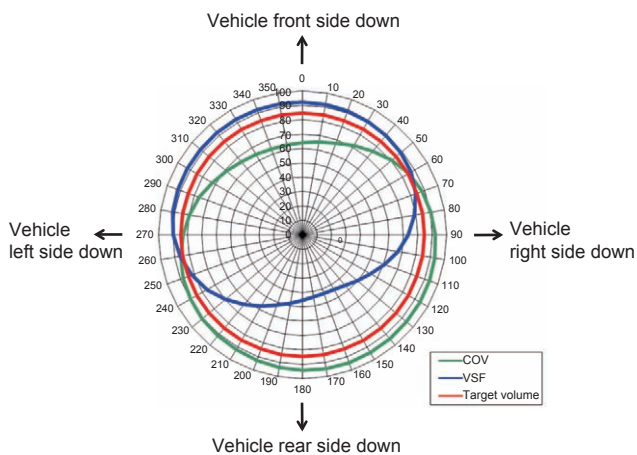


Fig. 11 Vapor-liquid separation performance

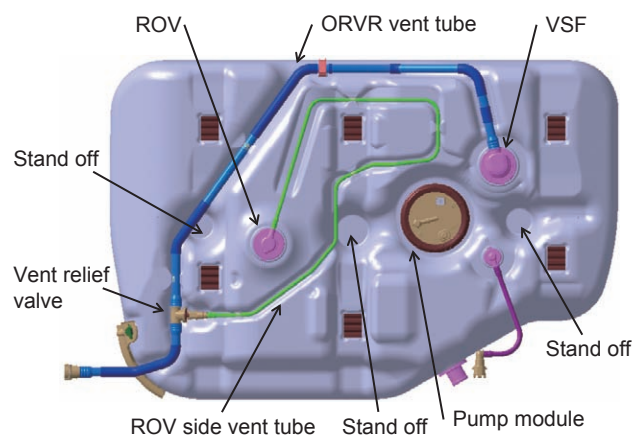


Fig. 12 Fuel tank assembly for 2011 model year Odyssey

5. Evaluation of System Soundness

5.1. 2-vent System – Total P-Q Characteristics

Vapor control is significantly different between a conventional system and the new 2-vent system.

In the conventional system, an optimal vapor flow setting for a refueling period can be achieved only by controlling and adjusting the P-Q characteristics of the vent relief valve.

In the proposed 2-vent system, the P-Q characteristics of the relief valve and of the VSF orifice must be considered at the same time. In other words, “total P-Q” control and adjustment is required.

First, the total P-Q characteristic of the entire system for the refueling period was verified to set the overall ventilation orifice size to $\Phi 1.4$ or equivalent. As shown in Fig. 13, this was attained through a VSF orifice diameter of $\Phi 0.8$ at two locations and a vent relief valve orifice diameter of $\Phi 0.8$ at one location.

These separate orifices were positioned to maintain vapor flow. Although the specific situation can vary based on the vehicle's inclination angle, vapor flow depends only on the VSF's P-Q characteristics when the ROV is submerged in fuel; thus the vapor flow passage is cut off when the main vent hole in the VSF is submerged. For this reason, a fairly large orifice size was set on the VSF side to maintain vapor flow.

Figure 14 shows the total P-Q characteristics of the 2-vent system, as well as the individual P-Q characteristics of the VSF orifice and relief valve.

The area requiring control during refueling and the area where the flow rate should be increased to prevent excessive pressure in the fuel tank were addressed by combining the VSF orifice characteristics

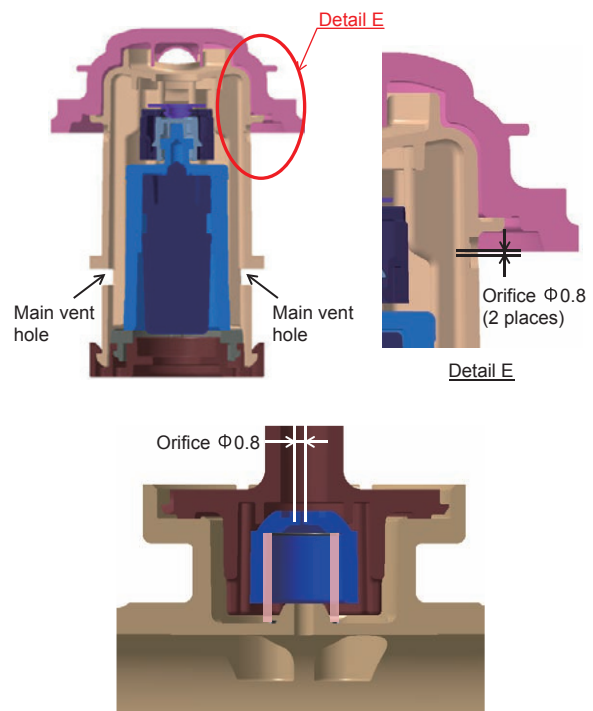


Fig. 13 Orifices for VSF and vent relief valve

with the characteristics due to opening of the relief valve. However, when vapor is passed through the main vent hole of the VSF, the pressure becomes low relative to the flow rate, at which time the P-Q characteristics do not apply.

5.2. Vapor Flow Characteristics at Diurnal Breathing Loss (DBL)

Although both the VSF and ROV achieve zero-level leak through their respective seals, the volume of fuel vapor generated was checked to confirm that the vent system met the required vapor flow performance and to evaluate any effect caused by a valve seal failure.

The condition where vapor flows only through the VSF orifices due to the vehicle's inclination occurs only near the full capacity of the fuel tank. Vapor flow needs to be maintained regardless of the pressure inside the tank. If vapor is generated by a change in outside air temperature while the vehicle is parked on a slope, no fuel leaks should occur. To confirm system performance, the temperature shift specified by CARB's Diurnal Breathing Loss (DBL) requirement was measured and vapor generation was checked under the condition of a leaking ROV seal.

Vapor generation was also checked in the condition where vapor was flowing only through the ROV and the VSF seal was leaking. The vapor flow was maintained and no fuel leaked to the canister. As shown in Fig. 12, a line connects each valve on the tank and prevents any fuel leakage.

Figure 15 shows how the fuel temperature and gasoline vapor generation in the fuel tank change due to a DBL temperature shift.

Given this data and the P-Q characteristics of the individual orifices shown in Fig. 14, it is clear that there is little pressure in the fuel tank as long as vapor is flowing.

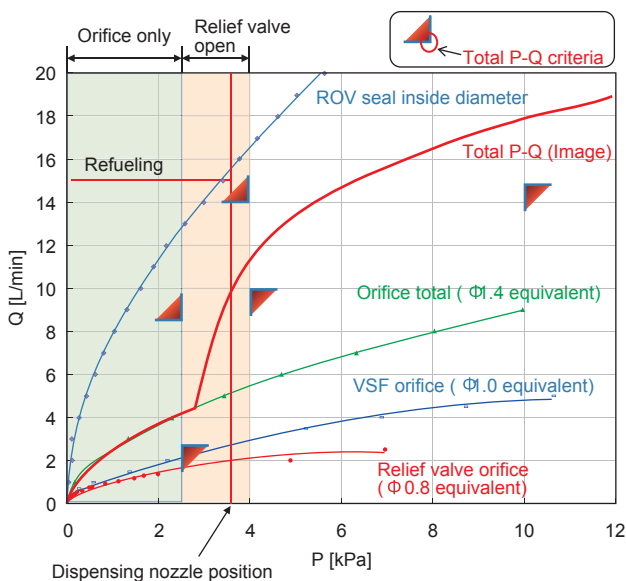


Fig. 14 Vent system P-Q characteristic

5.3. Refueling Performance

The operating pattern of the newly-adopted VSF and refueling based on the P-Q characteristics of the vent system were checked. Smooth refueling was possible until automatic refueling stop, and the volume of initial and subsequent refueling were confirmed to be at levels where the full-tank volume could be achieved. In addition, there was no spit-back of fuel after automatic refueling stopped and all targets set as initial technical requirements were met.

5.4. Evaporative Emission Performance

Evaporative emissions from the new system were evaluated according to the conditions under the LEV2 regulation. While the regulation specifies the full test based on 3 days of DBL from the entire system, and the short test based on 2 days of DBL, the development adopted a permeation target value of 200 mg or less per day from the system only. Figure 16 shows the evaluation results of 2 days of DBL from the fuel system components only. As shown, the new system meets the development target.

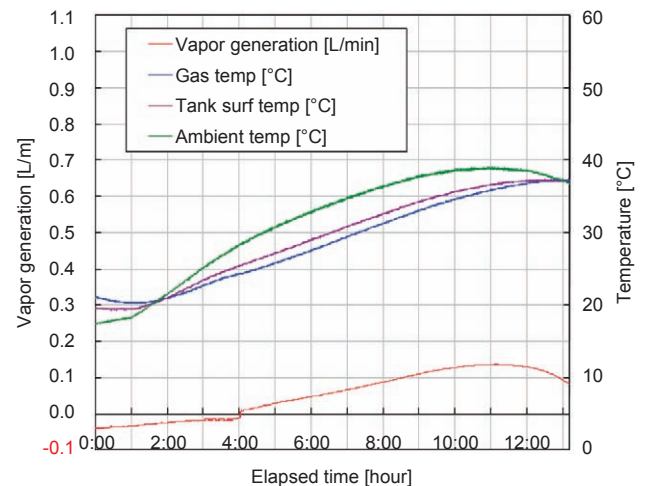


Fig. 15 DBL temperature and vapor generation

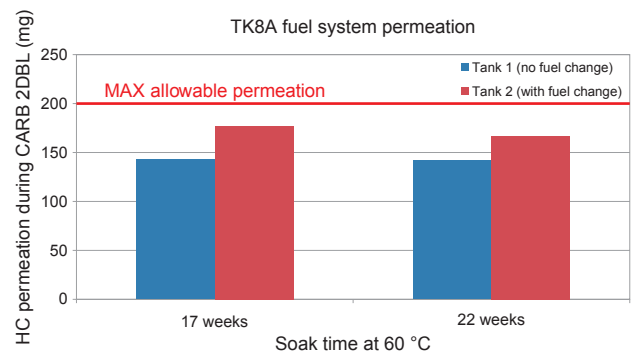


Fig. 16 Fuel system permeation (CARB 2DBL mode)

6. Summary

The outcomes of this development are summarized below.

- (1) The “2-vent system with zero-leak valves” technology was established.
- (2) Zero fuel leak level was achieved based on sealing between “plastic” and “rubber” materials in each seal area for both the VSF and ROV.
- (3) Zero fuel leak level was achieved, even in a fuel-submerged environment, by adopting a lightweight, external-force adsorbing design for each float.
- (4) Appropriate levels of marketability in terms of refueling, and vapor flow in an inclined state, were achieved by implementing total P-Q control of the vapor generating in the 2-vent system.
- (5) The fuel system development target for the 2011 model year Odyssey eliminated the vent tower while maintaining marketability in terms of low floor packaging, fuel tank capacity, and filling efficiency; reduced cost; and enhanced reliability.

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