EXPERIMENTAL INVESTIGATION OF LEVEL INDICATOR ERRORS CAUSED BY TURBULENCE IN VEHICLE FUEL TANKS

by

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According to the studies and customer feedback, the measurement results of the level sensors are reflected on the indicators approximately correctly. However, instantaneous erroneous measurements might occur in special cases (i.e. hill-downhill, rough terrain, vehicle acceleration, and deceleration). Existing fuel level measurement sensors are affected much by external factors because of their design (random vibration, sudden acceleration, vacuum because of sudden suction, etc.). Any unsteadiness that may occur in the fuel tank and the sensitivity of the fuel level measurement accordingly are investigated in this thesis study. Protected and unprotected fuel level sensors were tested under the same conditions by placing 25 L, 50 L, 75 L, and 90 L of liquid in the tank. Different unsteadiness speeds were applied to each volume to achieve the same unsteadiness effect. It has been observed that the changes between the maximum and minimum output resistance Decelerate from 30% levels to 2% for the unprotected type. As the speed increased from 10 rpm to 25 rpm, this difference became even more pronounced. In this way, it is affected less by the unsteadiness effect and the level measurement is made more sensitively.

Key words: *level sensors, fuel, level measurement, measurement error*

Introduction

The pressure tank in which the fuel that is required for the vehicle engine to operate is called the *fuel tank*, which is designed to store and use the flammable/explosive liquid in the tank safely. A fuel tank can be made of metal or plastic depending on the need and can usually be joined by welding the parts together. Plastic tanks can take more complex shapes depending on the vehicle's design. In this way, more comfortable design studies that can fit around axles and/or exhaust systems can be performed. Because of the more structured equipment, plastic tanks provide greater crash safety and provide better space utilization.

Inside the floating part, the reed switch is triggered by the magnet around the electronic board. It opens or closes the reed switch by triggering the reed switch corresponding to the liquid height in the tank with the rising or falling movement of the liquid. In both cases, the changing liquid level converts the magnet into an electrical on-off signal with the trigger of the reed switch and transmits the fuel amount information to the fuel level indicator. The pressure tanks in which the fuel that is required to operate the vehicle engine are stored are called *fuel tanks*. Liquid contact/non-contact sensors or mechanical solutions can be employed

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for fuel tank level measurement. Vertical floating buoy systems are generally preferred because they are more cost-effective.

The working principles of capacitive sensor, ultrasonic sensor, differential pressure transducer, and vertical moving float used in liquid level measurement have been discussed in different studies [1]. It was observed that the material of the tank to be employed, the type of liquid in the tank, and the pressure and temperature value of the environment are effective in the selection of the sensor to be employed for measurement. Apart from mechanical measurements, ambient conditions and sensor sensitivity, the density of the fuel and friction effects can also change the measurement accuracy [2]. By using an ultrasonic sensor for liquid level measurement, level measurement can be performed with sound waves without direct contact with the liquid. In these measurements, successful results were obtained at levels between 0-30 cm [3]. Imbalances in fuel tanks have also been addressed in different studies. The two different tanks (with/without curtain) were observed at 50-85% occupancy rates and with warnings in different directions, it was observed that instability caused sudden pressure changes. However, it has been observed that the curtain tank design is effective in reducing the pressure value of the liquid at the time of instability [4]. A detailed study has been conducted on the level measurement methods and they have been divided into two groups based on mechanical and electrical from time to time. In addition, ultrasonic measurement methods are also used to measure the level of liquid in a small tank. In some experimental studies, it has been seen that successful measurements have been obtained in the level range of 0-20 cm [5].

Theoretical and experimental studies were conducted according to different design styles, refueling rates, and linear motion direction of the fuel tank for the standard input value of the unsteadiness event in a passenger car fuel tank. In some studies, instability has been analyzed by making different designs such as curtainless, curtainless/floating and curtain/floating, and it has been observed that the baffle/floating tank structure has a more balanced pressure distribution and reduces instability movement [6]. The researchers have investigated a high-precision servo motor-driven mechanical solution that can measure the buoyancy of liquids and solids. As with any method, the level varied according to parameters such as the type and temperature of the measured substance, whether the tank was pressurized or open to the atmosphere, and the size and location of the tank in this measurement method. Although this application provides high precision in the measurement of liquids, it has been determined that special attention should be paid to parameters such as smooth and correct assembly in solids [7].

As well as mechanical measurement methods, it is possible to measure liquid without liquid contact. Without adding any measuring substance or device to the liquid, the precision of measurements made without contact with the liquid loses over time and gives erroneous results. The liquid level is measured using ultrasonic, temperature and humidity sensors in hybrid form, without depending on a single sensor, and can be easily adapted to liquid tanks of different sizes and shapes [8].

Different improvements were made in the study of the fuel tank to minimize measurement errors. The floating part (floating part) in existing level sensors is usually designed without protection. For this reason, it is very much affected by the unsteadiness effects in the warehouse. To avert this error mode, an enclosure is designed around the floating part. In this way, it is less affected by the unsteadiness effect and the level measurement is made more sensitively [9-12].

During the experiments, the experiences gained from different sources regarding the designs of fuel tanks and data security were also taken into account. Security vulnerabilities, failures and efficiency losses arose from errors due to the manufacturing processes and design of cases. For maintenance purposes, it is so vital to dismount cases and remove components in a short time. Different designs and improvement methods obtained from these studies were also examined [13, 14].

There have been different studies not only in the sense of fuel tanks, but also on combustion. Performance analyses were examined by applying different coating methods. Coated engines are now known to cause improvements in performance and emissions. But an excessive increase in NO_x emissions is described as a negative aspect of coated engines. For this purpose, many coating materials are applied to pistons and valves [15].

Material and methods

Before the test was performed, the fuel level measurement sensor was shaped to be mounted on the vehicle and attached to the fuel tank as the final product. The sensor head employed in the fuel level measurement sensor was produced from ABS-equivalent polyurethane material by silicone molding method [16]. The produced sensor head is shown in fig. 1. Other semi-finished products that constitute the fuel level sensor were provided by Nesan Otomotiv Inc. The installed fuel level measurement sensor is shown in fig. 2.

Figure 1. Silicone molding sensor head

Figure 2. Mounted fuel level sensor

The electronic card employed in the fuel level measurement sensor has a resistance output and shows the remaining fuel amount in the tank to the fuel level instrument panel in the vehicle according to the resistance value read depending on the level of the fuel at that time. The resistance values of the prepared fuel level measurement sensor that correspond to the fuel level in the tank are shown in tab. 1.

Table 1. Electronic board resistance table

H [mm]	439	418	397	376	355	334	313	292	271
R [Ω]	180	166.01	152.02	138.02	124.03	110.04	94.04	78.04	62.04
H [mm]	250	229	208	187	166	145	124	103	82
R [Ω]	46.05	30.05	14.05	8.49	7.59	6.69	5.8	4.90	4

The level measurement floating part was designed to be in direct contact with the liquid on the fuel level measurement sensor without protection in the first design studies.

Figure 3. Protected type fuel level sensor

Considering that the floating part that floats in the liquid can move up/down too much in case of unsteadiness, protection is designed around the fuel level measurement sensor. The protected type fuel level measurement sensor is shared in fig. 3. The protection pipe material plexiglass was preferred to observe the movement of the floating part in the liquid easily. Two fuel level measurement sensor types were tested and the measurement differences between them were compared.

The test equipment was produced by Nesan Otomotiv Inc. to show the operation of the fuel level measurement sensor on the vehicle. The fuel tank was supplied by the company and the test equipment, in which the unsteadiness effect could be observed, was manufactured by the same company. The test equipment enabled us to observe the measurement uncertainty that may occur by providing the unsteadiness that may occur on the vehicle. The test equipment, which operated fully and automatically free from the human factor, is automatically deactivated in case of a possible accident with the fuses and safety valves on it.

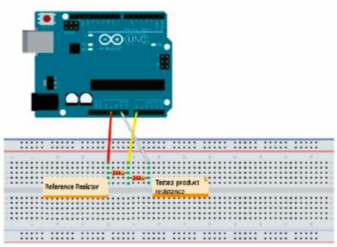

Figure 4. Arduino board circuit diagram and written program

Test equipment consists of four main parts in general. The first part is the fuel tank where the fuel level measurement sensor is attached. The second part is the sliding mechanism that allows the fuel tank to make the unsteadiness effect on the *x*-axis. The third part is the control panel, where the unsteadiness effect is controlled and sets the unsteadiness intensity. The fourth part is the Arduino and Arduino board, where the movement of the floating part that provides the fuel measurement of the liquid height formed during the unsteadiness of the fuel level sensor in the fuel tank can be controlled, and where the resistance values that occur depending on the movement of the floating part can be controlled. The program and circuit diagram written on the Arduino board is shown in fig. 4. With this program, the resistance changes because of the movement of the floating part on the fuel level measurement sensor in the tank were observed. The variability of the resistance values indicates the measurement uncertainty in the fuel level gauge. The test equipment on which the product tests are performed is shown in fig. 5.

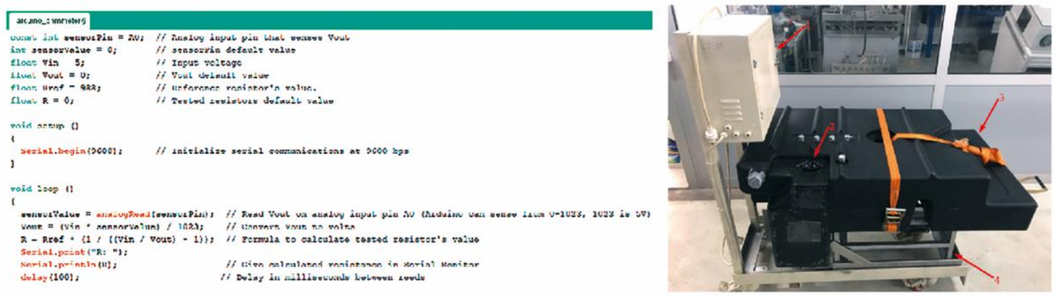

Figure 5. Testing equipment; *1 – speedometer instrument panel, 2 – fuel level measurement sensor, 3 – fuel tank, and 4 – slide mechanism*

In basic principle, in on-board tanks, whose maximum and minimum production tolerance and geometry are known as mathematical models, the unsteadiness that occurs with the acceleration of the fuel measurement system with a buoy, which is placed in the tank and is in contact with the liquid in the tank was investigated, and depending on this, the sensitivity of the fuel level as a result of the up/down movement of the level measurement buoy was examined [17, 18].

The tests of the fuel level measurement sensor were performed in the high-current life test device described in the experimental method section. The fuel level measurement sensor is mounted on the fuel tank that is attached to the slide mechanism. The purpose was to obtain real results by reflecting the unsteadiness intensities that might occur in the fuel tank depending on the movement of the vehicle (hill, descent/ascent, rough terrain, and sudden deceleration).

The volume of the fuel tank that was attached to the test was approximately 190 L. The movement of the floating part, which performed fuel level measurements at 10 rpm, 20 rpm, and 25 rpm, was observed by gradually putting 25 L, 50 L, 75 L, and 90 L of liquid into the tank. The resistance values that changed depending on the movement of the floating part were controlled by the Arduino. The visuals with the liquid heights and rotational speeds in the fuel tank are shown in fig. 6. The test was performed in both ways, where the floating was in direct contact with the liquid and by adding a protection piece around it, and the difference between the two cases was compared. The image of the fuel level indicator inside the tank after the protection piece is attached is shown in fig. 7.

Figure 6. Tank volumes and speed display

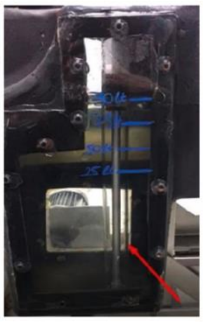

Figure 7. Protected fuel level sensor mounted version

Results and discussion

The tests were conducted in two ways, with the floating part attached to the fuel level measurement sensor in a free state, in direct contact with the liquid, and by passing a protection part out of the float. Two fuel level sensor types (*i.e.* protected and unprotected) were tested by adding 25 L, 50 L, 75 L, and 90 L of liquid in the tank, respectively, under the same conditions and the same unsteadiness effects. The resistance change because of the movement of the floating part during the shaking was recorded with the Arduino. Each combination was tested for one minute. The output resistance values were transferred to the computer medium and the measurement differences between the two types of fuel level sensors were observed. Protected and unprotected type fuel level measurement sensor outputs performed at 10 rpm, 20 rpm, and 25 rpm for different tank volumes were examined. As a result of the tests, it was found that the level measurement floating part was designed without protection on the fuel level measurement sensor, and it was affected by the unsteadiness in the fuel tank greatly.

It was observed that there was no change in the measurement stability of the protected-type fuel level measurement sensor as the liquid level increased. Table 2 shows the minimum and maximum resistance values in the graphs for 75 L of fuel. As seen in the table, the difference between the minimum and maximum resistance values of the protected-type fuel level sensor was less than the unprotected version. This shows the stability of the protected type in terms of measurement. The percentage of the change between the maximum and minimum output resistance values read was calculated. The changes of the maximum and minimum resistance differences is shared in tab. 3. When the resistance differences read as [%] were examined, it was seen that the difference was less in the fuel level measurement sensor, which is called the protected type, and in this context, the value to be read on the indicator was the closest to reality.

Table 2. Minimum and maximum resistance values (75 L)

	Minimum [Ω]	Maximum [Ω]
Unprotected/10 rpm	108.23	122.69
Protected/10 rpm	108.23	109.42
Unprotected/20 rpm	77.04	122.69
Protected/20 rpm	107.04	122.69
Unprotected/25 rpm	91.83	136.28
Protected/25 rpm	108.23	109.42

Table 3. The changes between the maximum and minimum output resistance

	25 L	50 L	75 L	90 L
	Percentage of change [%]	Percentage of change [%]	Percentage of change [%]	Percentage of change [%]
Unprotected/10 rpm	30	22	13	42
Protected/10 rpm	2	1	1	1
Unprotected/20 rpm	27	43	59	110
Protected/20 rpm	2	9	15	41
Unprotected/25 rpm	78	43	48	171
Protected/25 rpm	9	1	1	63

It was observed that the level of unsteadiness was very high, and the fuel liquid in the tank hit the floating part with a shock effect during any sudden acceleration of the vehicle, especially in models with asymmetric tank geometry. In such cases, it was determined in the analysis and design environments that the float moves too much up/down lost its sensitivity in level measurement, and sent the wrong level information to the vehicle electronic control unit (ECU) by making incorrect measurements, which will not only inform the user of the wrong fuel level in the vehicle ECU but also cause the needle on the level indicator to move up/down continuously. A delay can be created by using the *delay* function on the software in the vehicle ECU in this fault mode. In such a case, not a continuous datum is received from the buoy, but the measurement is made intermittently for the duration of the *delay*. The movements of the floating part can be somewhat deafened with this method. However, the floating may also give incorrect level measurement information to the vehicle ECU in some cases in the deafening technique performed with this method. Because the up/down movement of the float may be caught at the wrong position point and incorrect level measurement information may be sent to the ECU in extreme unsteadiness situations, no matter how infrequently the measurement frequency is made.

In such cases, it was determined that the up/down movements shift too much, and in this way, the lack of sensitivity in level measurement and incorrect level information is sent to the ECU by making incorrect measurements, which causes the vehicle ECU to display the wrong fuel level to the user and the needle on the indicator to constantly move up/down. In this erroneous mode, the frequency of fuel level measurement can be delayed after the delayed software in the vehicle ECU. After this process, the measurement is taken by slowing down during the defined delay time, not by constantly receiving data from the fuel level measurement sensor. With this method, the measurement uncertainty occurring in the fuel level measurement sensor can be somewhat deafened. However, with this method, the fuel level measurement sensor because of the delay may also give incorrect level information to the vehicle ECU in some cases. Because no matter how infrequently the measurement frequency is made, the up/down movement of the floating may be caught in an incorrect position and send incorrect level measurement information to the vehicle ECU in case of excessive unsteadiness.

Another method is possible with the parts of the breakwater to be added to the fuel tank. In other words, the fin-like parts to be placed in the tank can protect the floating part to some extent in case of sudden unsteadiness during the production of the fuel tank. However, this method is not considered appropriate in terms of technical, production, and cost. Because the manufacturing processes of fuel tanks are produced with very large molds, it is a very difficult method to put the breakwater parts into the mold. It is not possible to add breakwater parts externally after manufacturing. Also, even if the breakwater parts are added to the tank in some way, the distance to the floating part will be far and it will not be able to limit the unsteadiness at the expected levels in a large volume. In this case, the float may be affected by the unsteadiness and make level measurement errors.

Conclusion

A mechanical filtration design was made to prevent such situations and to reduce the error modes to zero. The floating part is in an unprotected structure on the float in the current design, therefore, it is affected by the unsteadiness very much. To avert this, a housing design was made around the float, which was designed to be monolithic with the float, and these error modes were reduced to almost a minimum. This damper unit creates a closed volume by taking the float on the float into a reservoir and avoids sudden unsteadiness and the effects of such unsteadiness on the floating part. In this way, the most accurate fuel level is transmitted to the vehicle ECU.

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