Development of Overflow-Prevention Valve with Trigger Mechanism.

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Abstract. A new overflow-prevention valve for combustible fluid is developed which uses a trigger mechanism. Loading arms for combustible fluid are used for transferring oil from a tanker to tanks and vice versa. The loading arm has a valve for preventing overflow. Overflow-prevention valves cannot use any electric component to avoid combustion. Therefore, the valve must be constructed only by mechanical parts. The conventional overflow-prevention valve uses fluid and pneumatic forces. It consists of a sensor probe, a cylinder, a main valve for shutting off the fluid and a locking mechanism for holding an open state of the main valve. The proposed overflow-prevention valve uses the pressure due to the height difference between the fluid level of the tank and the sensor probe. However, the force of the cylinder produced by the pressure is too small to release the locking mechanism. Therefore, a trigger mechanism is introduced between the cylinder and the locking mechanism. The trigger mechanism produces sufficient force to release the locking mechanism and close the main valve when the height of fluid exceeds a threshold value. A trigger mechanism is designed and fabricated. The operation necessary for closing the main valve is conformed experimentally.

1. Introduction
Overflow-prevention valves for combustible fluid are used in the tanker, tank truck, oil depots, gas station and refueling pomp. The overflow-prevention valve shuts off the fluid flow when the fluid exceeds a threshold level. The valve cannot use any electric component to avoid combustion. Therefore, the valve must be constructed only by mechanical parts. The conventional overflow-prevention valve uses fluid and pneumatic forces. It consists of a flow path, a sensor probe, a main valve for shutting off the fluid, a locking mechanism and an air cylinder. The sensor probe is a hole of inlet and outlet for the air which is connected to the air cylinder. The fluid level is detected by the blocking the air in the sensor probe. The main valve holds the open state by the locking mechanism. The cylinder closes the main valve by released the locking mechanism in emergency. There are three methods of generating the releasing force by the cylinder:

(a) Using negative pressure.
(b) External air pressure supplied.
(c) Using positive pressure.

The method (a) utilizes Venturi effect caused by fluid flows through a constricted section. The output of the cylinder is determined by the area of the piston and the applied negative pressure. The negative pressure depends on the flow velocity and the area ratio between the flow path and the constricted section of the Venturi pipe. The flow velocity increases at the constricted section. Static electricity may induces a fire due to the high flow velocity which is produced by the friction between the flow path and the
Therefore, the area of the constricted section cannot be so reduced. Moreover, the low flow velocity does not produce the required force by the negative pressure in the event of the emergency. Increasing the area of the piston can produce the required force in the low flow velocity. However, the mass of the valve becomes heavier according to the increasing the area of the piston. It will be a burden for the operator of the loading arm. Therefore, there exist upper and lower practical limits of the flow rate. Figure 1 shows a photograph of the conventional valve using negative pressure. This study is started to modify this valve. The original of the overflow prevention valve is for the loading arm of 3 to 4 inches (80 to 100 mm) inside diameter. It has a cylinder with a diameter of 200 mm. The one of purposes is reduced the size of the valve.

The method (b) uses high pressure from an external air source. This method does not need to increase the area of the piston. The cylinder generates the closing force by increasing pressure when the outlet of the sensor probe is closed by the fluid level in the tank. This is suitable for small valves or frequently used for example, in gas stations. One problem of this method is the necessity of a compressor as an external air source. The compressor must be installed far away from operation spaces because of electric power sources. Therefore, this is higher cost than other methods. This method is not suitable for overflow prevention valves that operates not so frequently.

The method (c) produces the required force by the height difference between the fluid level of the tank and the fluid level in the sensor probe. The valve can produce enough force by increasing the height difference between the fluid level and the sensor probe and increasing the area of the sensor probe. Therefore, the operator is required to deeply insert the heavier nozzle into the tank. Moreover, the flow path becomes relatively narrower by increasing the sensor probe diameter. The proposed overflow prevention valve is of this type. The height difference and the area of the sensor probe are reduced by inserting a trigger mechanism. The trigger mechanism produces sufficient force to release the locking mechanism and close the main valve when the height of fluid exceeds a threshold value. The trigger mechanism uses the lateral force between permanent magnets and ferromagnetic parts.

2. Proposal of new overflow-prevention valve

Figure 2 shows a model of the proposed overflow-prevention valve with the trigger mechanism (method (c)). The fluid flow in from the right hand side in the figure which flow out from the bottom. The pressure
in the sensor probe becomes higher than the atmospheric pressure along with the fluid level difference when the fluid level in the tank exceeds the fluid level in the sensor probe. The sensor probe is connected to an inner chamber of the cylinder mounted on the valve top. The higher pressure produces downward force acting on the piston. The generated downward force is usually insufficient to release the locking mechanism directly. Therefore, a trigger mechanism is inserted between the piston and the locking mechanism. The trigger mechanism has two stationary states corresponding to the open and closed states of the main valve. A spring in the locking mechanism stores potential energy when the main valve is opened by an operator. The trigger mechanism is at the upper position corresponding to the open state as shown in Fig. 2 (a). The trigger mechanism is pushed by the piston and transits to the closed state when the pressure exceeds a threshold value. The trigger mechanism generates larger force than the piston in transiting to the closed state. The generated force is enough to release the locking mechanism. As result, the main valve is closed shown in Fig. 2 (b).

Figure 3 shows a model of the trigger mechanism. It consists of a mover, a permanent magnet, an outer frame, upper and lower limiters. The mover consists of an axis, a stopper, an upper flange, a lower flange and a convex-shape body. They are made of ferromagnetic material. The permanent magnet and the limiters are fixed on the outer frame. The mover moves only the vertical direction in the center of the ring-shape permanent magnet fixed on the frame. The mover has two stationary states. In one of them, the stopper of the mover contacts with the lower limiter by attractive force between the permanent magnet and the lower flange (upward force). In the other one, the mover contacts with the upper limiter by downward forces. The downward force are generated by lateral force between the permanent magnet and the convex-shape body, attractive force between the permanent magnet and the upper flange, and gravity.

Figure 3 (a) shows the open state. The upward attractive force acting in the mover is stronger than the downward force. Therefore, the initial position of the mover contacts with the upper limiter. The contact force is determined by the relative distance between the mover and the permanent magnet. When the fluid level becomes high, the piston gives force to the trigger mechanism due to the increased pressure of the inner chamber of the cylinder. Figure 3 (b) shows the close state. The mover is displaced when the total downward force is stronger than the upward force. Because the force generated by the

![Fig. 2 Model of proposed overflow-prevention valve using positive pressure with trigger mechanism.](image-url)
permanent magnet inversely proportional to the gap, the upward force of the lower flange decreases as the gap between the lower flange and the permanent magnet increases, and the downward force of the upper flange increases as the gap between the upper flange and permanent magnet decreases. Then the mover is displaced to contact the upper limiter by the downward attractive force that exceeds a threshold. The trigger mechanism produces force required to release the locking mechanism and close the main valve.

The trigger mechanism must be designed carefully to operate in the above-mentioned ways. The relationship between the acting force and the displacement of the mover were measured with an external

![Fig. 3 Model of proposed overflow-prevention valve using positive pressure with trigger mechanism.](image)

(a) Open state
(b) Closed state

![Fig. 4 Relationship between displacement and attractive force.](image)

-60 -50 -40 -30 -20 -10 0 10 20

Force [N]

0 2 4 6 8 10

Displacement [mm]

Initial Position

Characteristics of locking mechanism

Measured characteristics of trigger mechanism

Analysis

1.8
displacement sensor and a load cell. The mover was displaced with a feeding mechanism. Figure 4 shows experimental characteristics and the analysis results using an FEM (Finite Element Method). The positive horizontal axis represents downward displacement. The displacement of 0[mm] shows the stopper contacted to the lower limiter (open state). The positive vertical axis represents upward force. The filled red circles represent the measured characteristics of the mover. The filled blue circles represent the analytical result by FEM. These results are included the downward force due to weight of the mover. The filled green rectangles represent the measured characteristics of the locking mechanism. In this case, the negative vertical axis represents upward force. From this result, to release the locking mechanism, a displacement of 5[mm] and a force of 22[N] are required to the trigger mechanism. The downward force due to the weight of the mover is including in this result. The mover contacts with a force of 9[N] to the upper limiter in the initial position. The displacement of the force acting in the mover changes upward to downward when the displacement of the mover exceeds 1.8[mm]. The trigger mechanism is displaced to the downward direction automatically. The downward force acting on the mover exceeds the upward force of the locking mechanism at each displacement. Therefore, the trigger mechanism generates the downward force of required for releasing the locking mechanism.

3. Design of pneumatic circuit
A pneumatic circuit is designed for generating a force of 9[N] and a displacement of 1.8[mm]. Figure 5 shows an analysis model of the pneumatic circuit. The compression of air is neglected because of small difference between atmospheric pressure and pressure of an inner chamber. The pressure of the inner chamber is generated by the height difference of the fluid surfaces between the tank and the sensor probe. The pressure of the inner chamber is

\[ p_d = z_1 \rho g \tag{1} \]

where
\( p_d \) : Pressure difference of cylinder chamber,
\( z_1 \) : Difference of fluid surface,

Fig. 5 Analysis model of pneumatic circuit.
\[ \rho \quad : \text{Density of fluid (}=750[\text{kg/m}^3]), \]
\[ g \quad : \text{Gravity acceleration (}=9.8[\text{m/s}^2]). \]

Therefore, the piston generates a downward force given by
\[ F_s = A_d \rho g \]

where
\[ F_s \quad : \text{Output of piston}, \]
\[ A_d \quad : \text{Area of piston}. \]

Moreover, the fluid flows into the inner chamber from the sensor probe. Its volume is same as the stroke volume given by
\[ V_s = A_p z_2 \]

where
\[ z_2 \quad : \text{Depth of fluid in the sensor probe}, \]
\[ A_p \quad : \text{Area of sensor probe}, \]
\[ V_s \quad : \text{Stroke volume of piston}. \]

From Eqs. (1) to (3), we get the inserted depth of sensor probe \( z_d \) as
\[ z_d = \frac{F_s}{A_d \rho g} + \frac{A_d l_s}{A_p} \]

where
\[ l_s \quad : \text{Displacement of piston}, \]
\[ z_d \quad : \text{Inserted depth of sensor probe}. \]

The symbol of the figure shows the following in addition.
\[ d_s \quad : \text{Diameter of piston}, \]
\[ d_p \quad : \text{Diameter of sensor probe}, \]
\[ F_b \quad : \text{Releasing force for locking unit (}=22[\text{N}]), \]
\[ l_b \quad : \text{Releasing distance of locking unit (}=5[\text{mm}]). \]

The diameter of the sensor probe and the diameter of the piston is designed based on this equation.

3.1. Design of sensor probe diameter
The diameter of the sensor probe is determined by assuming the diameter of the piston of 125[mm]. The inserted depth of the sensor probe can be reduced by increasing the diameter of the sensor probe. However, it reduces the effective area of the main flow path. Moreover, the velocity of the main flow increases due to the reduction of the effective area which should be avoided to protected fire. Therefore, the diameter of the sensor probe should be made as small as possible.

Figure 6 shows a relationship between the diameter of the sensor probe and the inserted depth. The inserted depth of the sensor probe should be approximately 200[mm] from a practical viewpoint. The conditions of the calculation is shown below.

Displacement of the piston: 1.8[mm],
Output force of the piston: 9[N],
Diameter of the piston: 125[mm].

The first and second conditions come from the results of the previous experiment. The diameter of the sensor probe should be 15[mm] or more to achieve the target inserted depth. The diameter of the sensor probe is designed to 19[mm].
3.2. Design of piston
Next, the diameter of the piston is selected. The diameter of the piston is desirable as small as possible because the loading arm becomes heavier by increasing the diameter of the piston. A heavy loading arm will be a burden for the operator. Figure 7 shows a relationship between the diameter of piston and the inserted depth of the sensor probe when the diameter of sensor probe is 19 mm. The conditions are same as the previous analysis. The diameter of piston is determined to be 125 mm to minimize the inserted depth based on this experimental result.

Fig. 6 Calculated value of relationship between inserted depth and diameter of sensor probe.

Fig. 7 Calculated value of relationship between inserted depth and diameter of piston.
4. Confirmation of closing valve
In this section, it is verified that the fabricated valve closes by fluid level difference between the tank and the sensor probe. Figure 8 shows a photograph of the fabricated overflow prevention valve using a trigger mechanism. It is set on the top of the conventional valve in the bottom. The main valve is at the center of the inlet. The trigger mechanism and the cylinder are assembled on the top of valve. A displacement sensor is attached to measure the motion of the piston on the top of the valve. The sensor probe is attached to a single-axis robot with an ultrasonic displacement sensor for measuring the inserted depth of the sensor probe. The sensors are used for the experiment only. In this experimental setup, the sensor probe is inserted by the single-axis robot into the tank filled with fluid instead of pouring fluid into the tank. Water is used for the fluid instead of oil in the experiment for safety. Therefore, the inserted depth is expected to increase by approximately 20[%] due to density difference when oil is used.

![Fig. 8 Photograph of experimental setup of proposed overflow-prevention valve.](image1)

![Fig. 9 Photograph of a trigger mechanism.](image2)
It is verified that the main valve is closed when the sensor probe is inserted depth of 150[mm] in the water tank. The inserted depth increases to approximately 180[mm] when the oil is used. This result agrees with the previous analysis.

The rate of increase of the fluid level depends on the tank shape. The rate is not constant in actual uses. Therefore, a relationship between the inserted velocity of the sensor probe and the inserted depth at the releasing was measured. Figure 10 shows the experimental characteristics. These results are the average of 20 data for each velocity. The inserted depth is larger as the inserted velocity increases. The inserted depth of the sensor probe becomes 210[mm] when oil is used in the rate of increase of the fluid level of 120[mm/s]. These results demonstrate that the developed overflow-prevention valve can operate a wide range of pouring speeds.

5. Summary
A new overflow prevention valve using a trigger mechanism was developed. The trigger mechanism used the lateral force between the permanent magnet and the ferromagnetic material. The pneumatic circuit of the developed valve was designed. That the developed overflow prevention valve successfully operated to close the main valve when the inserted depth of the sensor probe exceeds threshold values. The characteristics of the developed valve ware measured. It was confirmed to close by the proposed method.

References
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Special thanks
Mr. Chida and Mr. Kuroyabu made enormous contribution to experiment.