A Novel Semi-Passive Actuator for Drinking Water Tank Washer

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Abstract: -The objective of the present paper is to develop an innovative washer for washing the accumulated sewage inside drinking water tank. This new washer was composed of a semi-passive control actuator and electronic control module. Many outstanding characteristics such as easy installation, cheap, water-saving and friendly associated with this new washer. Especially, it was able to continue to supply pure drinking water with consumers during washing job was ongoing. When the waiting timer was time out, the washer actuator was energized, and then the solenoid value was alternately turned on and off depended on the setting value of duty cycle. Based on the water hammer effect, the actuator mechanism rotated along the radial axis of tank and wash simultaneously, and its velocity was dependent upon the length or diameter of sewage discharging pipe or the duty cycle of the solenoid valve of controlling electrical signals. In order to verify the feasibility and working performance about proposed new washer, the experimental prototype was first constructed in the laboratory. Moreover, experiments were carried out by using this prototype. Finally, those experimental results clearly point out that new developed actuator for drinking water tank washer is feasible, water-saving and operating friendly.

Key-Words: - Drinking water, water tank, semi-passive control actuator, duty cycle, solenoid valve.

1 Introduction

Drinking water is provided to consumers from the water purification plant that has been widely used in many developed country. For increasing the water pressure, most water consumers generally install a water reservoir or tank on the top stairs of buildings. As the economic increasing development, it become one of their important events in daily life for people desire to acquire high quality drinking water. Therefore, there are many countries will intend to invest much money to build purification station and change old water transmitting pipes. More and more experts and engineers pay their attentions on searching for obtaining high quality drinking water. As we have known that quality of drinking water is generally clean when leaving the purification station; but it is possible to be deteriorated on its transmitting process. Problems can often be correlated to the contamination in the raw water or occur caused by some parts of water in reservoirs being stagnant and create a growth of algae and bacteria.

On the basis of the observation of the turbidity condition inside consumers' water tank over a long time, the contaminated drinking water gradually accumulated in the bottom of water tank day by day. In case of the amount of contaminated water is excessive the limited level, it may be drunk by consumers. Hence consumers' health is threatened at any time. Problem can be solved by means of washing the drinking water tank every a constant time period. Conventionally, the washing work of water tank was done by manual approach. As a result of much more time and pure water is required for completing the washing job. In addition, it is very difficult to precisely predict the exactly washing time. Especially, it is very inconvenient for consumers are requested to stop using pure drinking water during washing job is ongoing. Therefore, not only the washing efficiency is worse and washing cost is inexpensive, but also the effect of this washing action upon consumers' daily life is very much. As a consequence, some kinds of automatic washer with special mechanisms are developed by designers. However, these new automatic washer actuators were generally designed using an electric motor to replace with manpower. When actuator starts to work, all drinking water which originally has been reserved inside tank should be discharged firstly. Furthermore, on one hand, pouring into pure water, and on the other hand, proceed to washing work of washer and discharging sewage simultaneously [1]-[5]. Additionally, there are existing another two significant drawbacks during the washing process, the first is the increasing cost of additional washer actuator is not cheap due to the requirements of extra motor and other facilities, and the second is this types of washer actuators must commonly stop supplying pure drinking water with the consumers during washing job is ongoing. Since most of these types of washer actuators are driven by electric motor and their additional facilities are iron-made, so that it should be lubricant for constant time period so as to prevent washer facilities from eroding. There is an essentially unfavourable factor is those equipments easily pollutes the water due to caused by the lubricant of the mechanism. It is not suitable for this type of washer actuator to be used in moisture environment. Otherwise the high quality of drinking water may not be ensured in mostly practical fields.

In order to pursuit of higher quality of drinking water for consumers, the research today is insistent on proceeding, lots of experts devote themselves to using different types of sensor systems to measure dynamic quality of water. For example, Buehler et al. [6] adopt a four-electrode conductivity probe and Wang [7] use the thick-film based sensors suitable for such measurements in determining the water quality. A lipid membranes designed sensor detects pollutants in water [8] and an optical fiber sensor system is presented to detect particle concentrations in water [9]. Water quality instruments used as a multi-sensor system is also presented in [10][11]. Many modelling approaches have been presented in the literature are able to simulate water quality using: 3D mathematical model [12], artificial neural networks [13] and fuzzy probability [15]. In order to acquire high quality of the drinking water to be widely used by consumers and prevent drinking water from supplying during washing job ongoing. As the turbidity level or the quantity solid suspended material, which accumulated in the bottom of water tank, is too excessive to drink, there is a special washer actuator is designed, called semi-passive washer actuator here. An electronic control module is integrated into the new washer actuator. After a constant waiting time period, the solenoid valve is alternately switched on and off by the output electric signals of electronic control module.

This study aims at developing a novel washer actuator which integrated with an electronic control module to complete the washing work for domestic drinking water tank. In addition to the essential washing functions of washer actuator was taken into consideration, especially, the control algorithm of electronic control module mainly resorted to be simple, water-saving, cost-effective, high washing efficiency, easy installation, and so forth.

Once the quantity of sewage inside tank is too excessive to drink, the sewage will be discharged by way of the bottom outlet of water tank. The leak out sewage can be directly reused to pour the plant or indirectly filtered by means of special filter facilities, and then injected back into the water tank. Since the structure of washer actuator mechanism is specially designed, therefore, the domestic drinking water supplying system not only is able to complete the washing work, but also does it continue to supply the pure drinking water with the consumers during washing job is ongoing.

The remainder of the paper is organized as follows. Description of system configuration of the new proposed washer actuator and relative theories are given in section 2. In section 3, we describe the operation principles of this new proposed washer actuator. In section 4, the designing idea and the operation principle of electronic control module will be described. Some simulations and experiments are performed, and their results are presented in section 5 so as to illustrate the feasibility of the proposed washer actuator and its control approach. Finally, in section 6 we outline the main conclusions.

2 Description of System Structure

With the reference of Fig.1, if atmosphere pressure p_{air} exists at both the liquid's surface and the pipe outlet, the pressure difference across the pipe is $(p_{air} + p) - p_{air} = p$. The mass outflow rate q_{mo} should obviously depend on p somehow. The water outflow rate is also dependent upon the value of its pressure. As we will soon see, in some cases the relation between q_{mo} and p is linear. In analogy with the electrical resistance relation, $i = v/R$, the linear fluid resistance relation is written as:

$$q_{mo} = \frac{p}{R} \qquad (1)$$

where R is called the fluid resistance. As shown in the Fig. 1, the washer actuator is controlled by a solenoid valve. For each of constant waiting time period (it can be modified in term of the application conditions such as the using life of pure water transmitting pipes and the quality of raw water in purification station), the energized electric signal and duty cycle of solenoid valve is generated by the electronic control module. The defaulted duty cycle of solenoid valve is set about 50%. In other words, the solenoid valve is energized in the first half a working cycle, and then the valve is open and the sewage in the bottom of the water tank will be discharged by way of the discharging pipe; in remaining half of working cycle, since the electric signal is not present, the valve is closed and the rotation mechanism starts to rotate due to the water hammer effect.

The hydrostatic pressure due to the water height h is:

$$p = \rho g h \quad (2)$$

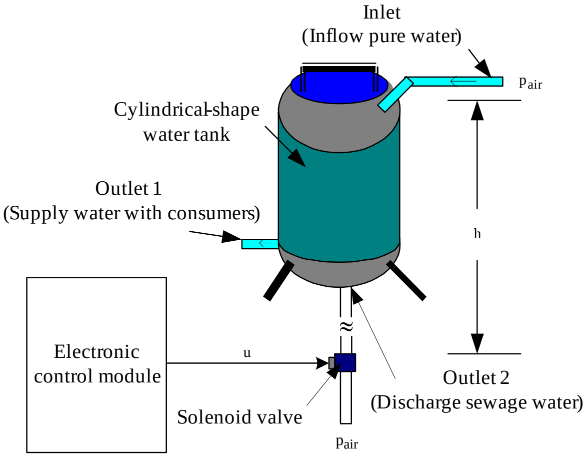


Fig. 1 Configuration of new proposed washer.

Typical drinking water tank and electronic control module is shown in Fig. 1. Generally, there is an outlet in the bottom and the mass of discharged sewage is controlled by one solenoid valve. Note that the outlet of supplying pure water with consumers is set higher than that of the discharging sewage pipe. In many application fields, the cross-section area of tank is the largest among all of the orifices in the system. In case of the height of liquid inside tank is h, the outflow velocity v of the fluid through the outlet orifice for discharging sewage can be described by Torricelli's principle, and the expression is represented as follows [15]:

$$v = \sqrt{2gh} \quad (3)$$

where the g and h represents as the acceleration of gravity and dynamic liquid height of the water inside tank, respectively.

2.1 Mass of Flow

Based on the conservation of linear momentum to determine the force exerted on an object as a result of emitting or absorbing a continuous flow of mass (here means that water leak out from discharging outlet). The resulting equation applies to a variety of situations, including the forces exerted on objects by flows of liquids.

Suppose that an object of mass m_0 and velocity $\vec{v}_0$ is subjected to no external forces, as shown in Fig. 2(a), and emits an element of mass Δm_f with velocity $\vec{v}_f$ relative to the object, as shown in Fig. 2(b). We denote the new velocity of the object by $\vec{v}_0 + \Delta\vec{v}$. The linear momentum of the object before the element of mass is emitted equals the total linear momentum of the object and the element afterward:

$$m\vec{v}_0 = (m - \Delta m_f)(\vec{v}_0 + \Delta\vec{v}) + \Delta m_f(\vec{v}_0 + \vec{v}_f) \quad (4)$$

Evaluating the products and simplifying, and taking the limit of this equation as $\Delta t \to 0$ we obtain:

$$-\frac{dm_f}{dt}\vec{v} = m\vec{a} \quad (5)$$

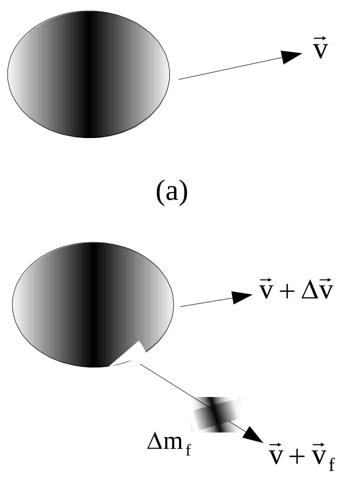


Fig. 2 An object's mass and velocity (a) before and (b) after emitting an element of mass.

where $\vec{a}$ is the acceleration of the object's center of mass and the term dm_f/dt is the mass flow rate, the rate at which mass flows from the object. Comparing this equation with Newton's second law, we conclude that a flow of mass from an object exerts a force on the object:

$$F_f = -\frac{dm_f}{dt}\vec{v}_f \quad (6)$$

This force is proportional to the mass flow rate and to the magnitude of the relative velocity of the flow, and its direction is opposite to the direction of the relative velocity. In contrast, a flow of mass to an object exerts a force in the same direction as the relative velocity [16].

2.2 Water Hammer and Its Effects

Water hammer occurs, for example, when a valve at end of a long pipeline is suddenly closed. The abrupt reduction of the fluid velocity to zero causes a shock wave to travel up the pipe at a velocity approaching the sound speed in the fluid, causing a large pressure rise. The shock wave is reflected as an expansion at the reservoir supplying the fluid at the upstream end, which reverse the fluid velocity. This expansion wave in turn is reflected at the valve as another expansion wave. Usually this expansion will cause cavitations that are the production of pockets of air, which have been formerly dissolved in the fluid, and of fluid vapor. This process is repeated several times with reduced intensity. The location of the cavities may be localized or extended for some distance along the pipe. This has a considerable influence on variation of pressure at point remote from the valve, and on the rate of decay of the pressure waves. The ability to monitor the presence of the cavities is of considerable value. The most commonly used formula for calculating pressure rise is [17][18]:

$$p_h = 0.07 \times \frac{v_h \times L}{T_h} \tag{7}$$

where parameters in (7) are defined:

p_h : is the pressure rise above static pressure (kg/m^2);

v_h : is the velocity of flow ($m/sec.$);

L : is the length of pipe on pressure side of valve (m);

T_h : is the closing time of the valve, solenoid valve closing time is approx. 40-50ms under normal operation condition (second).

As shown in (7), the sufficient strength of the solenoid valve is only utilized to make/break the fluid flow and properly regulated the operating duty cycle simultaneously. As the strength of the pipeline is sufficient to overcome the effects caused by the water hammer, the rotation mechanism of washer actuator not only rotates along the center axis of tank, but also does the accumulated sewage water which lies in the bottom of the tank through the sewage discharging outlet. As a result of the control scheme and mechanical structure is easy, safe and feasible. Indeed, there is an inevitable result can also be deduced from (3), the more length of sewage discharging pipe, the more rotating velocity of the rotation head should be obtained. Verifying results concerning with this subject are going to be found in the section five of this paper.

3 Operation Principle of Washer Actuator

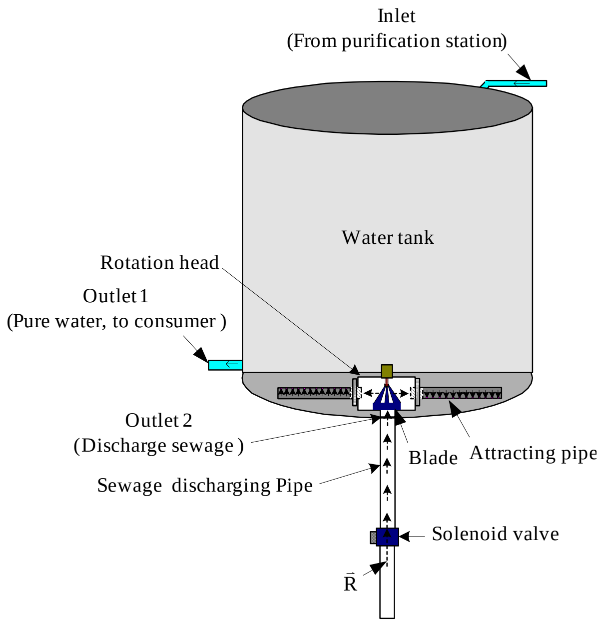
The basic structure of proposed new washer actuator is drawn and presented in Fig. 3. It essentially consists of four physically setups: rotation mechanism, sewage discharging pipe, and controlled solenoid valve. The reasons of positioning the relative facilities are described as follows:

(a) Rotation mechanism: This is a significant part of washer actuator, which includes four sewage attracting pipes and a rotation head. The tilt angle of sewage attracting pipes can be respectively programmed by a corresponding screw bolt, as shown in Fig. 3(b). When the solenoid valve is turned on by an output electric signal of electronic control module, the accumulated sewage on the bottom of water tank will be discharged by way of four attracting pipes, sewage discharging pipe and outlet (namely the outlet 2 in Fig. 3(a)). When the valve is suddenly turned off by enabling the electric signal to be absent, as a result of the water hammer effect therefore a reaction force $\vec{R}$ exerted by the solenoid valve. This reaction force then is transmitted and next feedback to the water tank through sewage discharging pipe and four attracting pipes. According to the Newton's second law principle, the reaction force will be divided into two parts, refer to Fig. 3(b): namely horizontal force vector f_h $(= f \cos\psi)$ and vertical force vector f_v. The vertical force vector would be none of rotation contribution with respect to the shaft of the rotation head; consequently, the resultant force exerted on the rotation head of rotation mechanism will be formed by four horizontal force vectors which caused by individual attracting pipe.

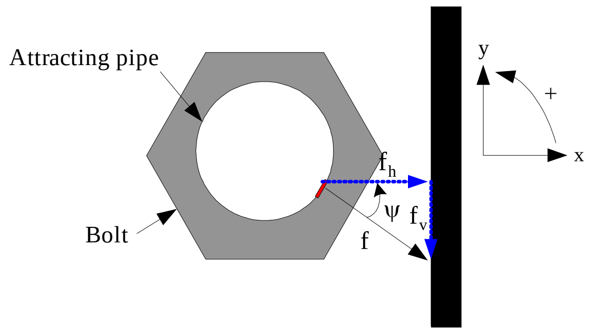
(b) Sewage discharging pipe: In (3), it indicates that water outflow rate varies proportionally with the level of water inside tank. The more the water level (include the water level and the length of discharging pipe) or the diameter of sewage discharging pipe, the more the water discharging velocity will be obtained. Equation (7) also reveals that the water hammer effect becomes obviously larger due to the change of water outflow rate is suddenly changed when the turned off time of solenoid valve is very short.

(c) Attracting pipe: There is four attracting pipes are mechanically coupled with the rotation mechanism. They are used to absorb the sewage when the solenoid valve is turned on; on the contrarily, transmitting the anti-force of water hammer due to the solenoid valve is suddenly turned off.

(d) Solenoid valve: When an appropriate voltage is applied to the solenoid's coil, there is no action about rotation mechanism, however, the sewage which accumulated in the bottom of inside tank is discharged by way of four attracting pipes and sewage discharging pipe. Contrarily, when the electric signal is not present on the coil, the rotation mechanism of washer actuator will rotate along the shaft of the rotation head due to the resultant anti-force of water hammer effect. Note that the washer actuator only works on duty cycle, so that it is called semi-passive actuator.



(a)



(b)

Fig. 3 Dynamic motion principle of new washer actuator (a) constituting mechanism (b) forces vector.

4 Motion Control

As above mentioned, the requirement of additional facilities such as electric motor and brushes are required for the conventional automatic washer to complete the washing job. When electric motor starts to work and drive the rod, since the brushes are coupled with the rod with mechanical mechanism, thus on one hand they are driven to rotate, and on the other hand washing the inside surface of water tank too. Therefore, in order to increase the washing efficiency, generally, it is popularly used approach to pour into pure water simultaneously. Finally, the sewage is leak out by way of the outlet of discharging pipe.

In many application cases, through observation over a long time, there is only raw water which would be contaminated and small dirty particles will be accumulated in the bottom of water tank, none of the growth of algae and bacteria. If counting from the top of water tank, almost two-thirds of the length of the water level inside water tank is pure and clean, certainly, it is not necessary to leak out all the inside water for proceeding to the washing job. As a result of the water saving and washing efficiency are taken into account, the new developed washer only absorbs the accumulated sewage in the bottom of water tank and leak out by way of outlet of discharging pipe. Upper part of drinking water inside water tank, it is almost not contaminated as above mentioned, physically, consumers are naturally able to continue to use the upper part of drinking water during washing job is ongoing.

The accumulated sewage in the bottom of water tank is absorbed by the washer actuator when washing job starts. Using the solenoid valve is alternately controlled on and off here, since the water hammer effect is caused by the solenoid valve is suddenly turned off. The new washer actuator on one hand rotate itself when the solenoid valve is turned off, and one the other hand also absorbs the sewage and leak out from the outlet of discharging pipe when the solenoid valve is turned on. During washing job is ongoing, the pure water flowing from the purification station is kept on injecting to the tank, and consumers are able to proceed to use the drinking water inside tank. In addition, the solenoid valve is not always turned on during washing cycle, but only work on part of washing cycle time, In other words, the washer actuator is controlled by a semi-passive control approach

The Fig. 4 shows that controlling configuration of new developed washer actuator for drinking water tank using semi-passive control approach. In addition to the basic controlled objective, the new washer also includes a set of washer actuator, electronic control module and power amplifier (may be included in electronic control module too). For convenient explanation, interior constituting functional block of electronic control module is exploded and shown in Fig. 5. Furthermore, in order for running well the control module, there is two types of setting time must be set firstly, namely the waiting time and washing duty cycle of washer respectively. When the waiting time is over, the washer actuator will be energized and then the washing job will start. Next work of washer is according to the setting duty cycle value, the washer actuator is then called as controlled by using semi-passive control approach. Through a bi-stable circuit and power amplifier, not only does the working and resting time of solenoid valve be alternately and automatically controlled, but also it can be controlled by manual method. In order to clearly describe the operation principle of electronic control module for new washer actuator, the controlling flow-chart is diagramed and demonstrated in the Fig. 6 as well.

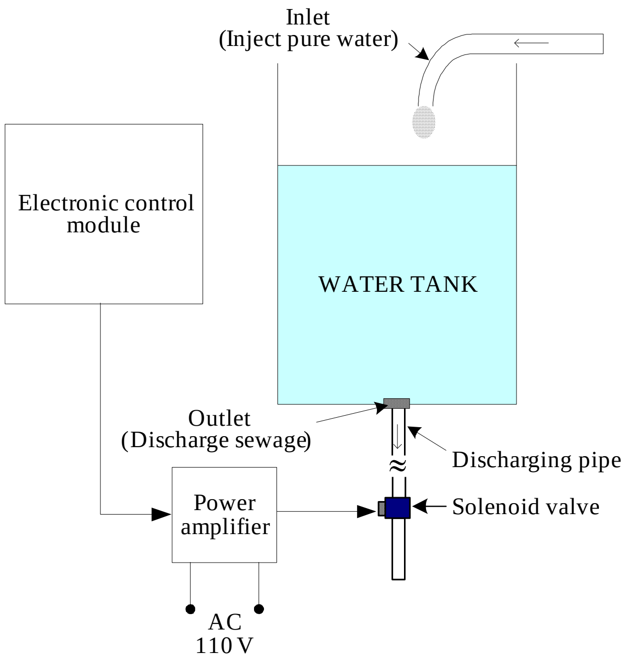


Fig. 4 Basic controlling configuration of new washer.

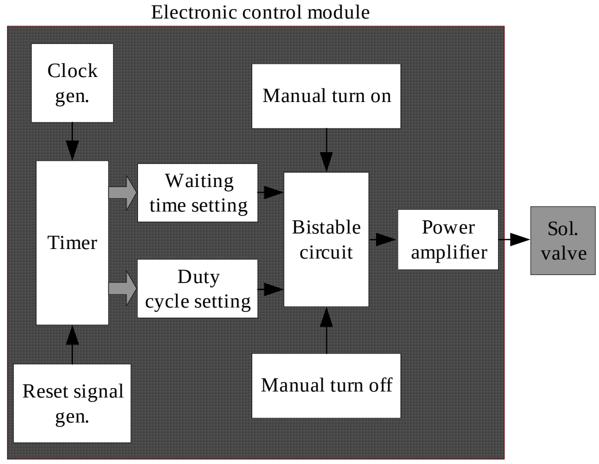
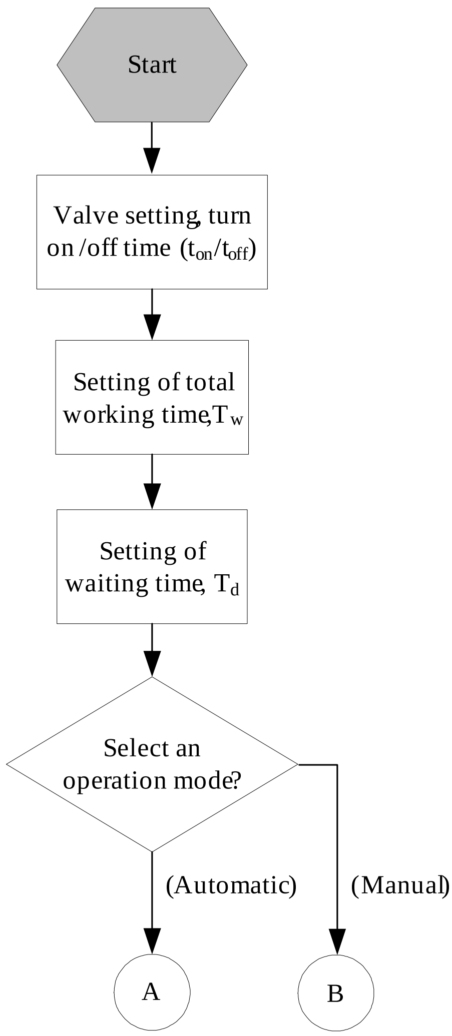
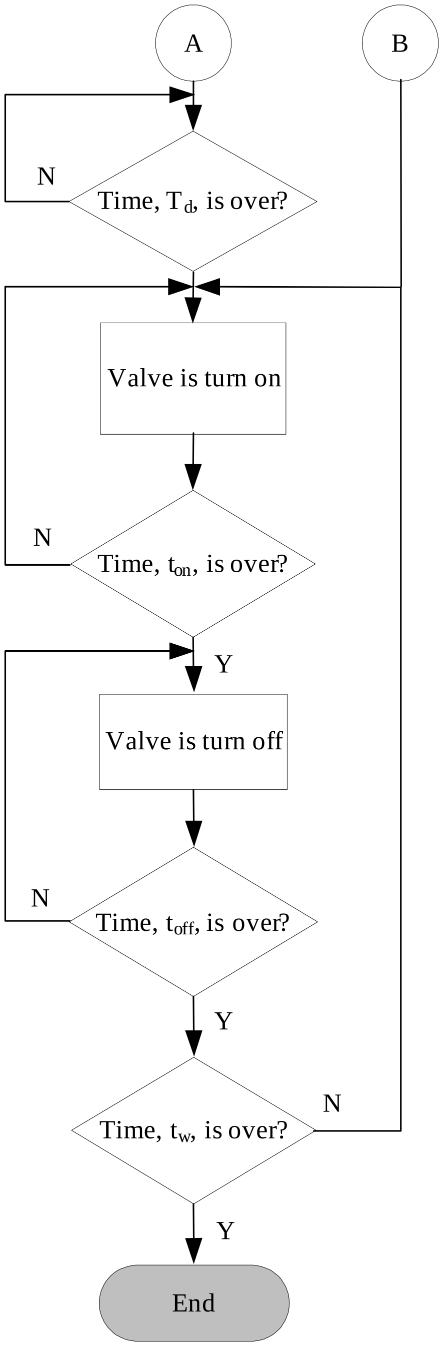


Fig. 5 Control functional block diagram of electronic control module.



(a)



(b)

Fig. 6 Controlling flow-chart of the electronic control module of solenoid valve.

5 Laboratory Tests and Results

The new developed washing system for dinking water tank has built and tested experimentally in a laboratory environment. Concerning with the important electrical specifications of solenoid valve is listed in Table 1. Photograph of completed water tank prototype for the requirements of experiment in this study is also shown in Fig. 7. As Fig. 7 shows, washing system prototype consists of a water tank body, washer actuator, control valve, and electronic control module. Theoretically, in order to test the effect of different length of sewage discharging pipes on the washing efficiency, several experiments were performed and the results are presented in the next subsection.

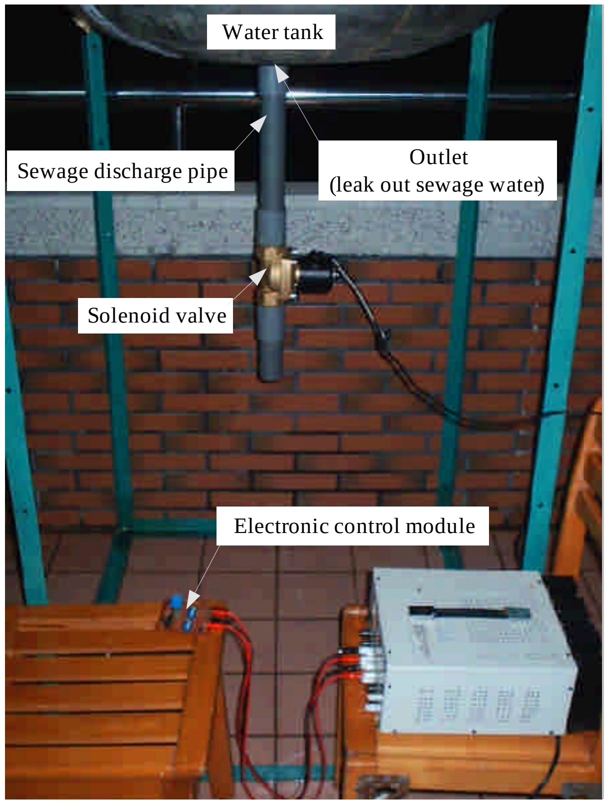


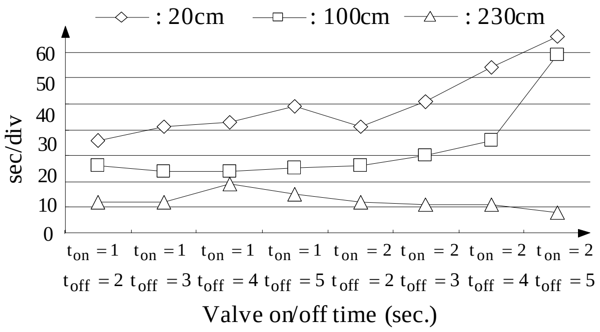
Fig. 7 Photograph of completed new washer prototype.

All the experiments were carried out by using the implemented prototype, as shown in Fig. 7, to confirm the functions and performances of proposed new semi-passive washer actuator. By means of integrating with electronic control module, which can well realize the superior advantages such as water-saving, high washing efficiency and easy operation for a popular utilized drinking water tank. Moreover, these characteristics were verified through the dynamic washing process of new washer was successfully recorded on film. When the washer is energized, new washer first achieves initialization action and next continues to rotate along a unifying direction. As shown in Fig. 8, the washing velocity of new washer depends on some important factors, for example the length of discharge pipe 20 cm, 100 cm, and 230 cm and with or without blades, detailed experimental data are listed in Table 1. The experimental results revealed that if it is necessary to rotate faster, larger diameter of sewage discharging pipe was needed or the length between the outlet of sewage discharging outlet and solenoid valve has to be lengthened.

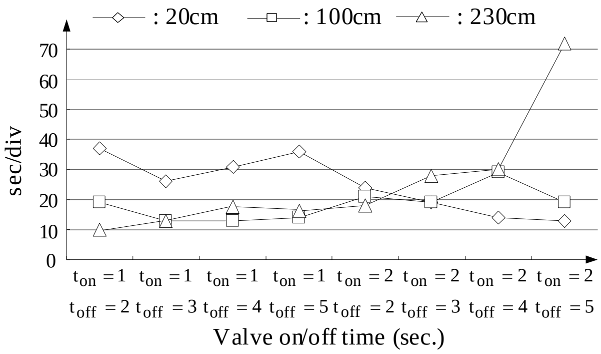
As the Fig. 8 shows that rotation head of washer with blades would have a much better washing efficiency than that of without blades under different lengths of the discharging pipes. Although some of the results without blades spent less time for attracting pipes move toward a division. Because the blades have been installed on each of attracting pipe intend to make a disturbance on the bottom of water tank for promoting the washing efficiency of washer. In addition, when washing operation starts, it is very obvious phenomenon that rotating velocity of the attracting pipe varies proportionally with the water level at that time.

Table 1 Experimental data.

Parameters	Data	Unit
Diameter of discharge pipe	38.1	mm
Length of discharge pipe	20, 100,230	cm
Diameter of attracting pipe	6	mm
Inlet diameter of attracting pipe	19	mm
Water level	16~34	mm
Tilt angle of attracting pipe	45	deg.
Total capacity of water tank	2000	ℓ

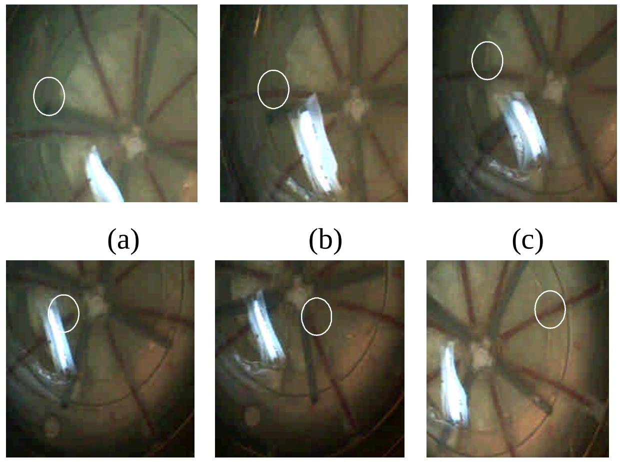


(a)



(b)

Fig. 8 Rotating velocity curves of rotation mechanism under the lengths of sewage discharging pipe are respectively 20 cm, 100 cm, 230 cm, , and (a) with blades (b) without blades.



(a) (b) (c)

(d) (e) (f)

Fig. 9 Continuous photographs show that dynamic working of semi-passive washer actuator during washing job is ongoing. (Note that pipe which is marked a white circle).

Stable washing is aimed at the purpose of no sewage waves occur in the bottom water-tank, and hope to effectively complete washing job. Moreover, the new developed washer actuator is inexpensive and easily retro-fitted into existing installations. Fig. 9 shows that a continuous sequence of six pictures of new proposed washer prototype during washing job is ongoing status. Corresponding performance comparisons between conventional and proposed control approaches have been conducted and presented in Table 2. By comparisons, the new proposed washer in this paper, as listed in Table 2, clearly indicated that has several superior characteristics that conventional washer without. In particular, none of similar designs were studied before, therefore, it is an original means for its innovative designing features, such as power-saving, water-saving and especially need not stop supplying water with consumers during washing work ongoing etc.

Table 2 Comparisons between conventional and proposed methods.

Item	Conventional method	Proposed method
Power-saving	X	O
Water-saving	X	O
Efficiency	X	O
Equip. cost	X	M
People cost	O	X
Additional apparatus	M	M
Stop supplying under washing	O	X

O : Large M : Medium X : Small

6 Conclusion

One innovative washer actuator which integrated with an electronic control module for a cylindrical-shape drinking water tank is developed in this paper. On the basis of a solenoid value is controlled by a semi-passive control approach. The washing job of water tank is done by an innovative washing mechanism, and it has never been previously addressed. Through a number of experiments are performed, experimental results are sufficient to verify the feasibility and performance of the developed washer. Especially, it is the best advantage that new washer actuator can continue to supply drinking water with all consumers during washing job is ongoing. An important direction for future work might study the intelligent prediction method, like fuzzy logic or genetic algorithm, to more precisely predict the water quality and then further is integrated with the proposed control techniques here.

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