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**PROTOTYPE DEVELOPMENT FOR A LEAK-PREVENTIVE
TOILET FLUSH SYSTEM – AN MET SENIOR DESIGN
(CAPSTONE) PROJECT**

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Abstract

A senior design (Capstone) project for three mechanical engineering technology students at Old Dominion University is described.

A prototype design is presented to perform the functional test of a leak-preventive toilet system. There are two major leaks in the toilet water tank. In the first case, leaking occurs when the seal in the water tank becomes aged. The leak is very easy to detect visually, since the outside of the tank and the floor becomes wet. In the second case, leak occurs when the flapper valve can't complete shut off the water, due to corrosion or damage of the rubber components. Water will flow down to the toilet through stand-up tube. The leaking may be very difficult to detect, since it may not be noisy and can't be detected visually. Although there have been several ideas proposed to solve the leaking problem, they are either impractical or need critical adjustments during the installation. Also, the operation is usually different from regular flush systems. In this project, students are asked to develop a leak-preventive prototype by modifying the concept of a dual-valve system.

In addition to functional analysis, students also consider the factors of manufacturing, installation, operation, design reliability, and adaptability to typical flush systems. Results show that the prototype can prevent the leak very effectively and can be applied to two major toilet flush systems. By using a magnetic activating mechanism in this design, the user won't feel any difference when compared to the operation of either of the flush systems.

I. Introduction

A very important part of engineering technology education is the use of senior design (capstone) projects to provide students with the opportunity to apply knowledge gained in other courses to solve a design problem. Mechanical engineering technology students at Old Dominion University usually take such a course in their last semester of study. Small groups of students (usually two) work on projects identified from one of several sources. A primary source of projects is local industry, usually small in size. Many of these companies do not have the engineering staff to investigate new products or make major improvement in their manufacturing processes. Contacts with these companies may be initiated by faculty members, the company itself, the college's Technical Application Center (an in-house organization that specializes in promoting economic development for the region through matching industry needs with faculty expertise and university facilities), or by students themselves who may be working for one of the companies. While student projects may vary substantially, they must all contain certain elements: design analysis, computer generated drawings, vendor contact, literature search for products and manufacturing techniques, material selection and if possible prototype manufacture and testing. The project described in this paper was brought to the faculty member by the Technology Application Center.

II. System Description

Figure1 shows an example of a toilet flush system. When a person activates the handle on a toilet, the flapper valve (Part 3) will be opened for releasing the water to the toilet. The float (Part 1) drops and water starts to refill the tank immediately. As the level of water in the tank rises, the float also rises and eventually shuts off the water-inlet valve, which will stop further flow of water into the tank. According to the studies^{1,3}, leaks occur during the following situations:

- (1) The rubber seal around the flapper valve loses its functionality because of aging and corrosion: With the leak water drains slowly into the toilet bowl and may go undetected for a long period of time. This problem also increases monthly water bills.
- (2) The force to push the water-stop valve (Part 5) is not enough: It may happen when the float is aged and the pivot mechanism (Parts 4 & 2) becomes fractured. The situation will also go undetected for a long period of time before being discovered. In this case, water will leak through the stand-up tube to the toilet.
- (3) Water tank is damaged: This situation can be easily detected visually, since the floor will be wet.
- (4) The water-stop valve loses its function: In this situation, the water will keep leaking until a new valve is replaced.

If the water leak remains undetected for a long period of time, a substantial amount of water can be wasted or, worse, very extensive damage caused. Situations may be even worse in hotels or motels, where some toilets are not frequently used¹. Therefore, some modifications to the current flush systems were proposed to solve the problem.

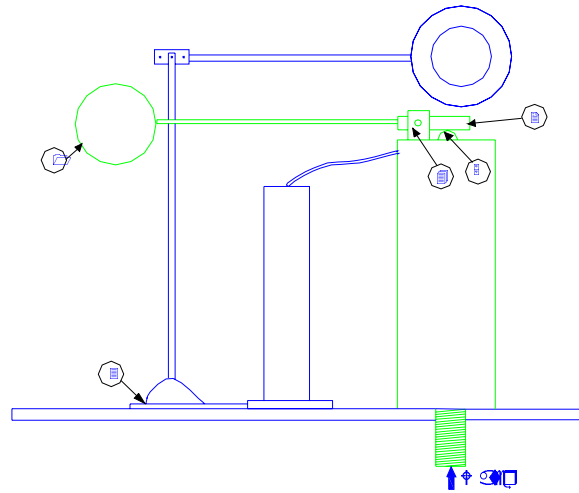


Figure 1: Example of a toilet flush system.

The student found that, according to the U.S. patents, there are three inventions presented to prevent the water leaks: (1) latch attachment for float operated valves², as shown in Figure 2, (2) toilet tank ballcock with detent arm¹, as shown in Figure 3, and (3) dual-valve control system, as shown in Figure 4. The main goal of the inventions is that, when nobody activates the flush system, no water will be allowed to fill the tank. If there is a leak, the water will leak out in the tank, but no more water will be allowed to flow to the tank.

Figure 2 shows the invention of the latch attachment for float-operated valves. A hanging pendulum (Part 1) is added to hook the arm (Part 2) which is controlled by the float of a commercial flush system. The pendulum holds the arm at the shut position until a person activates the mechanism. Although the design is a good idea, proper installation of the mechanism is almost impossible. This is because when the water level changes because of a leak, the pendulum won't be able to keep the valve at its shut-off position. Also, the idea can't be applied to other flush system.

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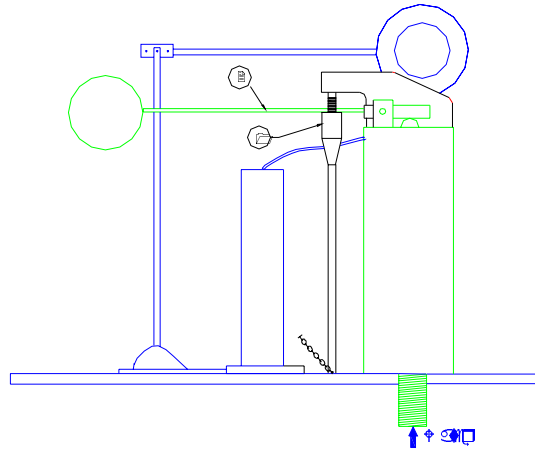


Figure 2: Latch attachment design.

In Figure 3, an adjustable detent arm (Part1) pivotally mounted above the ballcock float system is to swing into a latching position below the float and thereby prevents the float from lowering except pursuant to an intentional flush of the tank. The mechanism seems to be effective, however, adjustments are needed because of different water shut-off levels. The user needs to keep holding down the activating handle until the float (Part 2) goes down. From the nature of the design, the mechanism can't be applied to the other flush system shown in Figure 2. In addition, because of the weight of the mechanism, a user will feel a heavier resistance when activating the flush system.

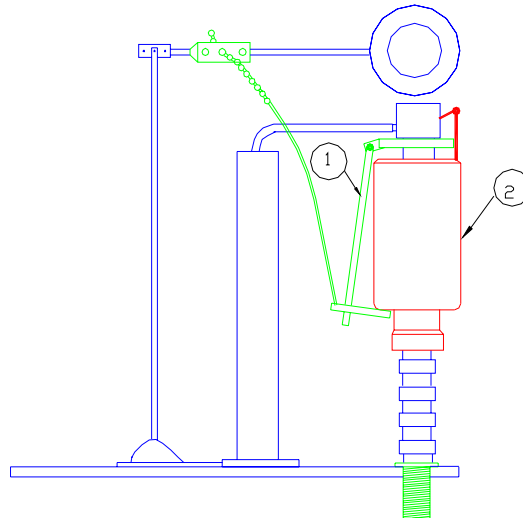


Figure 3: The ballcock mechanism.

Figure 4 shows a dual-valve control system³. In addition to the top valve that all the flush systems have, a pin valve (Part 3) is added to the bottom of the stand-up tube. When a person activates the handle, a small activating pin (Part 1) is extended to push one end of a pivot mechanism (Part 2). The other end of the pivot mechanism opens the pin valve (Part 3). The water flow then pushes up a weight saddle (Part 4) and water starts to fill the water tank through the stand-up tube. When water reaches the shut-off level, the top valve is closed and the water flow inside the stand-up tube is also stopped. The weight saddle then sinks and pushes the pin valve back to the shut-off position and completes the operation cycle. In this design, if the pin valve is not activated, water is always in the shut-off position. Therefore, if there is a leak, water won't be allowed to fill to the tank.

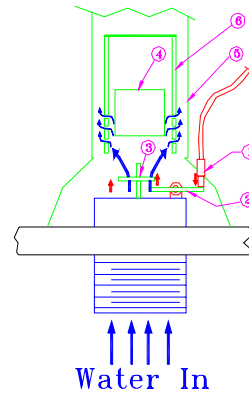


Figure 4: Original conceptual design of a dual-valve system.

Although this design provides a good direction, it faces the following problems:

- (1) When the bottom valve is activated, water will go through the hose of the activating pin (Part 1) to the activating handle and shoot out of the water tank. The problem will also generate noises when water is shooting out.
- (2) The stroke of the activating pin is very critical to the design. If it is too short, the activating pin won't be able to open the pin valve. If it is too long, a reaction force will be generated to cause damages on the pin valve and at the mounting area of the activating pin. Besides, designing a mechanism to control the stroke is another problem. The design will not only increase the manufacturing cost but also need adjustments during and after the installation.
- (3) Because of the nature of the pivot mechanism, the base diameter of the stand-up tube will have to be enlarged, as shown in Figure 4. The situation will cause problems when applying the invention to different flush systems. The pivot mechanism may be clogged after being used a long period of time. Also, because

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of the weight of the new design, the user will also feel a heavier resistance when compared to the operation of regular flush systems.

Based on the natures of the inventions given in Figures 2 and 3, these two designs can't be applied to other flush systems. Therefore, students were asked to redesign the dual-valve control system by meeting the following requirements:

- (1) No water shoot out is allowed.
- (2) The diameter of the stand-up tube must be at its minimum size so that the design can be applied to different flush systems.
- (4) The user should not feel a heavier resistance when compared to the operation of regular flush systems.
- (5) The design must be reliable.
- (6) Installation of the system must be similar to that of the major flush systems.

Students were divided into two groups to perform the functional design. One group was to design the mechanism inside the stand-up tube and the other one to design the activation mechanism. They were also requested to make their prototype models and perform the functional tests.

III. Modified design and operating procedures

When considering the requirement of not allowing water to shoot out of the water tank, the stand-up tube could not be drilled. Therefore, the force transmitted from the user to the pin valve could not be conventional. The two student groups worked independently and as a unit in brain storming for solutions, after several ideas were investigated and deemed unfeasible, the idea of using the nature of magnets⁴ to achieve the purpose was adopted. Figure 5 shows the modified design. When a person pulls up the cord (Part1), the magnetic force (Part 2) pushes the pin-stop block (Part 3) to the right and leaves an opening space for the pin (Part 4) to move up. Water starts to flow into the tank through the stand-up tube. The mechanism is simpler than the design given in Figure 4 and, as a result, the diameter of the stand-up tube could also be minimized to 2.0 inches. Furthermore, since the weight of the magnet is very light, the user won't feel a heavier resistance when compared to the operation of regular flush systems. Response of the mechanism was almost instantaneous and there was no need to keep holding the activating handle, such as the design problem given in Figure 3.

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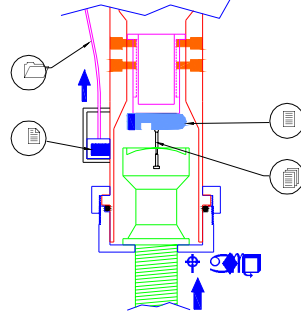


Figure 5: A magnetic activating mechanism.

Three prototypes were manufactured and tested for the design functionality and reliability. Operation procedures of the new design are as follows:

- (1) Initially, the top valve (Part 9) is closed and there is no water flow inside the stand-up tube. Figure 6 shows the situation.

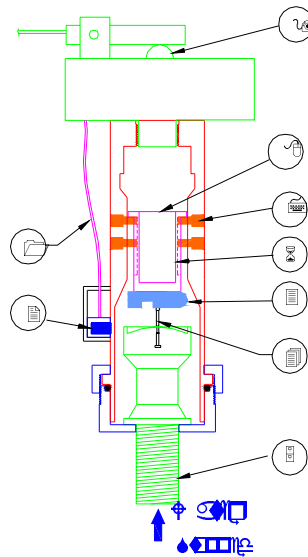


Figure 6: No water flows.

- (2) As shown in Figure 7, when a person activates the flush system, he/she also pulls up the magnet (Part 2) to the top position. The magnet then pushes the pin-stop

- block (Part 3) to the right. In the meantime, the top valve is already opened and water starts to push the pin (Part 4) against the opening space of the pin-stop block (Part 3) and opens the pin valve. Water starts to fill the stand-up tube and flow into the tank immediately (Operation and modification of the pin valve is described in Appendix A.).
- (3) In Figure 7, the four screws (Part 7) are used to control the linear movement of the weight saddle to reduce the noises when colliding with the inner surface of the tube. Figure 8 shows that water starts to fill the tank through the stand-up tube. The magnet drops back to its original position due to the gravity after the user releases the activating mechanism.

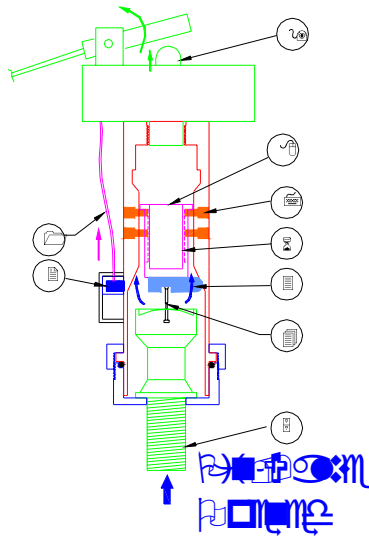


Figure 7: Water starts to fill the stand-up tube.

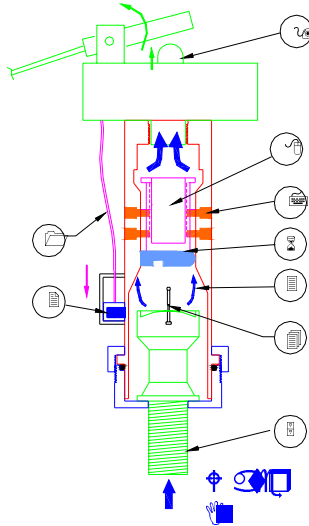


Figure 8: Water starts to fill the tank.

- (4) When the float reaches the shut-off level, it will shut off the top valve (Part 9) and water is stopped.
- (5) When water is completely closed or when the water force inside the stand-up tube is smaller than the weight of the weight saddle, the weight saddle will sink and push the pin valve back to the closed position. In this case, the pin-stop block is pushed back to the left by a taper surface inside the stand-up tube (Part 6). Therefore, the block will push the pin valve back to its closed position, as shown in Figure 6.

In this design, if a leak occurs inside the tank, water won't be able to flow into the tank. This is because the weight saddle still shuts off the water through the lower pin valve until a person activates the system. The tank becomes empty and a person will be able to know that a leak has occurred. From Figures 9 and 10, it is shown that the system can be easily modified to fit two major flush systems.

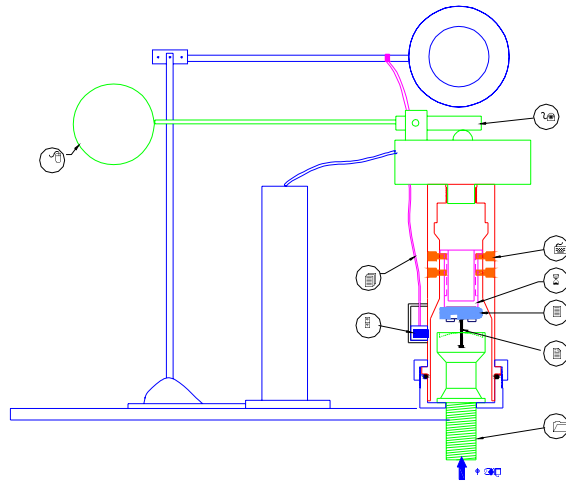


Figure 9: A dual-valve system is added to a commercial flush system.

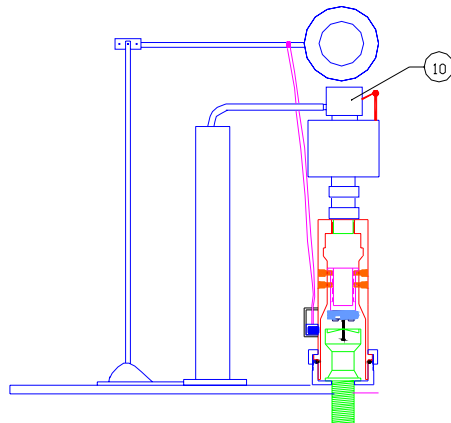


Figure 10: The dual-valve system is easily modified to fit another flush system.

IV. Summary

In this project, students converted a conceptual design to a functional design of a product by considering the factors of manufacturing, installation, operation, reliability, and adaptability to different flush systems. A dual-valve system was re-designed, manufactured, and tested to stop leaks for a toilet system. Results show that a person can easily install the system without having special techniques and he/she won't feel any difference when compared to the operation of a regular flush system. In addition, since there is no drill on the stand-up tube, operation of the system is as quiet as that of a regular flush system.

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Appendix A: Operation principle of the pin valve

One of the key components in this design is the use of pin valve, which is also applied in one of the commercial float systems (Part10 of Figure 10). Operation procedures and a modification to this valve are as following:

- (1) When the pin is at its lowest position, water (shown in arrowheads of Figure 11) goes through the top level of the rubber and stops the water. Since the water-seal area (downward arrowheads in Figure 11) is larger than the inlet area (upward arrowheads in Figure 11), water is at shut-off position. One can see that the force required to push the pin down is very small.

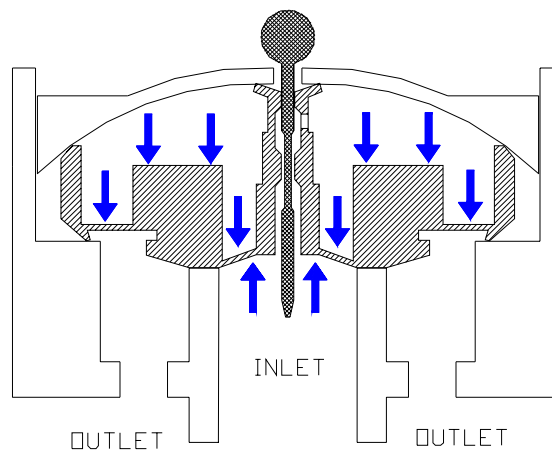


Figure 11: The valve is at shut-off position when the pin is pushed down.

- (2) When the pin is at its highest position, as given in Figure 12, water escapes from the top area of the rubber. Figure 13 shows that, due to the unbalance of the water pressure on the top and the bottom sides, water pushes the rubber up and starts to fill the tank. To make the pin functional, position of the pin movement must be well controlled by the activating mechanism.

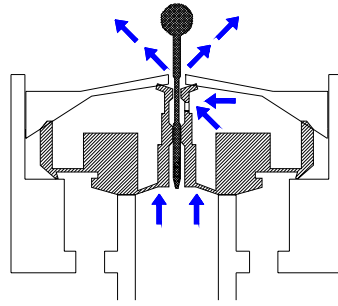


Figure 12: Water escapes from the top when the pin is pushed up.

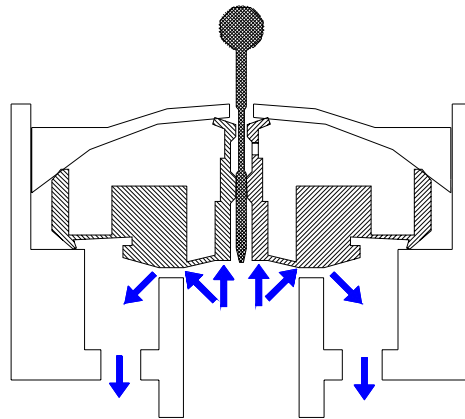


Figure 13: Water starts to fill the tank when the pin is pulled up.

- (3) In this design, since water will push the pin against the opening space of the pin-stop block, the pin may be off its position. Therefore, a small block is welded to the bottom of the pin to control its movement, as given in Part1 of Figure 14.

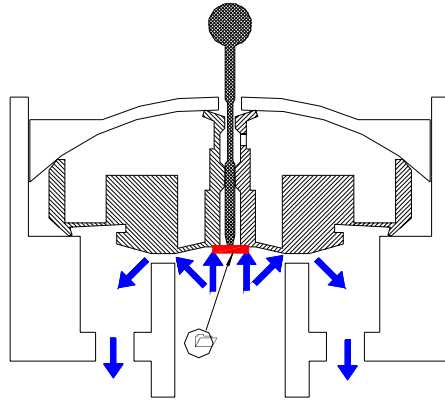


Figure 14: A stop block is added to the bottom surface of the pin.

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