Foot-Operated Device for Controlling the Flow of Water into Plumbing Fixtures

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Abstract

For so many years the use of the hand - operated valve has been in existence for use to control water flow into plumbing fixtures. This research report outlines attempts to solve the problems arising from hand recontamination associated with the existing means of water flow using manual control valves and the harbouring and breeding of germs related to the automatic faucet by designing a device to be controlled by foot for regulating water flow into the plumbing fixtures. This device can be adopted for use in places like homes, hostels, schools, offices, restaurants, healthcare centres and other public places in general.The design employs the use of a helical compressive spring (under varying loads) as the major component for keeping the plug of the valve and the pedal of the actuator (both linked by a control rope) in position instead of the screw as employed in the hand - operated valves, as the main principle of operation.The maximum input force accommodated by the actuator in order to open the valve at full port is 36 N for users of ages ranging from 15 years and above. Difficulties encountered (but solved) included sizing components and drawing.

Keywords: Hand – operated; Valve; Control; Water; Flow; Plumbing fixtures

1 Introduction

1.1 Plumbing Elements and Codes

Plumbing is the system of pipes, drains, fittings, valves, valve assemblies, and devices installed in a building for the distribution of water for drinking, heating and washing, and the removal of waterborne wastes, and the skilled trade of working with pipes, tubingand plumbing fixtures in such systems (Anon., 2013a). Plumbing activities are carried out both in domestic households and in the industry for some purposes such as fluid supply as well as for drainage systems. The fluid considered here can be water supplied hot or cold by a water company through street water mains into households for use in domestic activities such as drinking, washing, bathing, cooking as well as for waste disposal as in the case of flushing toilets after using the water closet. In the industry too, plumbing is done to control the movement and distribution of industrial fluids such as chemicals and other fluids for industrial activities Plumbing as a means of providing a drainage system can be either for sanitary and storm water drainage.Sanitary drainage systems carry bodily and other wastes from the plumbing fixtures and appliances by gravity through a sewer to a sewage treatment facility outside the building.Storm-water drainage systems carry rainwater from the roof by gravity through a sewer to a body of water or to a dry well.

Codes govern the plumber in the execution of his duties (installation of pipes and plumbing fixtures), the violation of which brings about problems such as stagnation of waste (gas and liquid in places where plumbing works are done. Some examples of plumbing codes violated include inadequate drain slope, unvented traps, flat venting, inadequate air gaps, inadequate space around toilet and basing. The plumber is to find out of these codes and comply accordingly. (Kardon,1999). Ensuring the compliance of plumbers to plumbing codes ensures efficient pluming work and avoids inconveniences such as those stated under common code violations related to plumbing. Clean water is not a luxury, safe clear drinking water and sanitation is possible in any nation, big or small, when simple, sound plumbing practices are adopted (Anon., 2013b).

1.2 Plumbing Pipes

Pipes for plumbing vary in diameter depending on whether their applications are for the supply of small or large amount of material or fluid. They are made of so many materials, selection of which depends on the application of the pipe (the type and properties of material being handled and the temperature conditions of the pipe environment). These materials may be either metallic or non-metallic (such as polyvinyl chloride (CPVC); for cold and hot water services as well as domestic plumbing and polythene (PEH); for water distribution, sewage, industrial effluent as well as gas distribution. The use of some metals (which contain some elements like lead in excess) as pipe materials is unsafe and harmful to the body. The chemical composition of the metal selected as a pipe material must therefore be properly considered.

1.3 Pipe Joints and Couplings

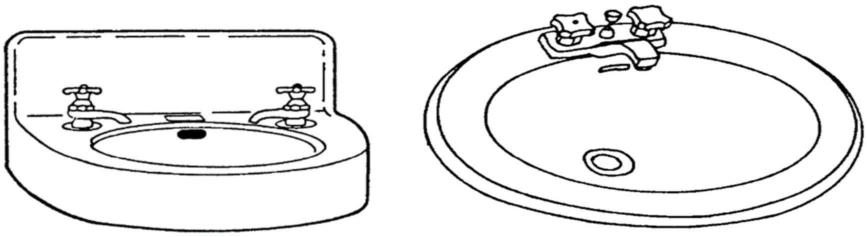
The type of pipe and methods of jointing used to give satisfactory service depends on factors such as diameter, material, pressure rating and other service requirements and facilities available.

1.4 Tools for Plumbing

These include tools for bending (like hydraulic pipe bender, and pipe bending machine), for cutting (like hacksaw, ratchet pipe cutter, RA pipe cutting machine, cutters for plastic pipes, disc cutter for wet cutting asbestos-cement pipes and guillotine pipe saw (Warring, 1982), for tightening (adjustable wrench, chain wrench, ring spanner and pipe wrench).

1.5 Plumbing Fixtures

Plumbing fixtures (such as water closet, lavatories, sinks, showers, bathtub, laundry tubs and drinking fountain) receive water and discharge waste into a sanitary drainage system to serve as a means of protecting the health of inhabitants both in domestic and public buildings (Anon., 2013c). These fixtures are provided to help get rid of waste in and on the body (urinating, removal of human excrement from the body and bathing respectively) as well as supply good drinking water.



(a) Wall-Hang (b) Vanity

Fig. 1 Lavatories
(Source: Anon.,2013c)

Fig. 2 Kitchen Sink
(Source: Anon., 2013d)

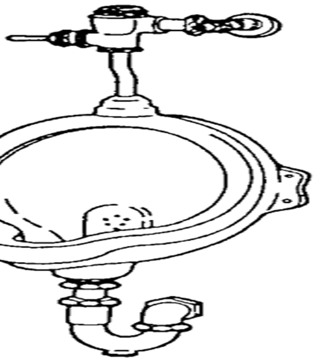


Fig. 3 Wall-Hang Urinal (Source: Anon., 2013c)

2. Manual Control of Fluid Flow Through Plumbing Fixtures

2.1 Manual Operation or Control of Devices

Manual operation or control requires the presence of a human being to provide the energy to operate the valve, as well as to determine the proper action (open, closed, or a throttling position). Manual operators require some type of a mechanical device that allows the human being to easily transfer muscle strength or mechanical forceinside the valve, usually through a hand wheel or lever that provides mechanical leverage (Anon., 2004).

Controlling water through the aforementioned plumbing fixtures is mostly by the use of the hand to operate a valve (faucet; hand operated water valve). Because the manual control of valves mostly involves touching of the valve handle to allow and stop water flow, it has the problem of recontamination of the hand after using them.

Whatever contaminant being picked during the operation of a faucet depends on, the area under consideration; it may be drops of urine at the urinal, traces of blood at the operation room in a hospital, chemicals and other toxins at the laboratory and other source of contaminations to think of.

The issue of contamination is very serious because it means that the intention of the fixture being used as a means of protecting public health will not be realized. The contaminants involved may pose serious health problems that may demand a lot of time and money to get rid of or control. The diseases and complications may be: measles, rashes, cholera, typhoid, diarrhoea and guinea worm, and poisoning when the contaminant involved is a chemical.

Aside contamination, other problems may be, misuse of water in the case where one forgets to close a valve. Elderly people with arteritis may find it difficult to operate. Parents always have the problem of ensuring that children always close faucets.

2.2 Automatic or Touchless Means of Flow Control

Most automatic faucets are battery powered and incorporate a passive infrared sensor to detect hand motion. Automatic faucets are common in public washrooms, particularly in airports and hotels, where they help to reduce water consumption and reduce the transmission of disease causing microbes. They can also be found in some kitchens and in the washrooms of some private residences. Other uses include providing drinking water to pets or livestock, whereby the presence of an animal allows water to flow into a watering trough or dish.

Automatic faucets have the advantage of shutting off automatically after hand washing, thereby reducing water waste. When installed in a home, sensor faucets alleviate the need for parents to ensure that children have turned off the faucet. They can also benefit the elderly and those suffering from arthritis or other mobility limiting conditions since there are no handles to twist or pull.

Though automatic faucets have lots of benefits, it may not be used in most developing countries because of its use of energy to power them. Another problem that is associated with the use of automatic faucet is that presentedby SHEA, 2011.

‘Electronic-eye, non-touch faucets have been increasingly utilized in healthcare settings to lower water consumption and in an attempt to reduce recontamination of the hands of healthcare personnel.

Cultures obtained from the faucets showed that 50 percent of water cultures from electronic faucets grew Legionella spp. compared to 15 percent of water cultures from manual faucets. Sydnor also found that 26 percent of water cultures from electronic faucets had significant growth on heterotrophic plate count (HPC) cultures, an estimate of the number of bacteria in the water, compared to 13 percent of water cultures from manual faucets. While the HPC rates were not statistically different, Sydnor believes the differences are worth noting.

Additionally, following a flush of the water system using chlorine dioxide the disparity between electronic and manual faucets persisted. After the cleaning, 29 percent of electronic faucet cultures were still contaminated with bacteria compared with seven percent of manual faucet cultures.

Sydnor speculated that the increased bacterial growth in electronic faucets may be due to contamination of the numerous parts and valves that make up the faucet. During the course of collecting water samples, researchers discovered that all of the electronic faucet parts grew Legionella spp.’

2.3 Controlling Water Flow into Plumbing Fixtures by Foot

From previous literature on the hand operated and automatic valve it is evident that the foot operated valve if well designed is the safest. This is because it is an improvement of the hand operated valve; it eliminates the problem of recontamination.

As will be considered, the design of the foot operated valve will not involve the use of so many parts that will serve as a breeding ground for germs as in the case of the automatic faucets. The use of a spring loaded foot operated valve in this application makes it better compared to the hand operated valve; it is self- return, water is not wasted, children will not be checked to find out if valve is close, sinks will not over flow because of forgetfulness to close valves.

2.4 Manual Control Valves

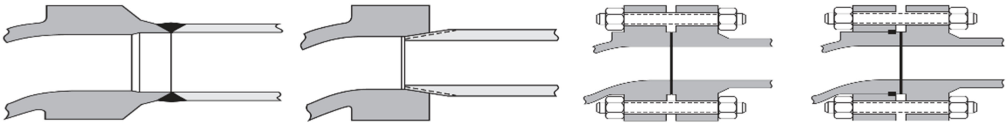
A control valve is defined as a mechanical device that fits in a pipeline creating an externally adjustable variable restriction.The purpose of a control valve is to provide the means of implementing or actuation of a control strategy for a given process operation. Control valves are normally regarded as valves that provide a continuously variable flow area for the purpose of regulating or adjusting the steady state running conditions of a process (Macdonald, 2008). Valves are used for both domestic and industrial purposes.

2.5 Valve Specification and Selection

This involves classification of valve by function, specific type, port size (full and reduced), and general service.

2.6 Body End Connections

A number of different end connections are available that allow the valve to be joined to the system's piping. In most cases, the valve's end connection is designed or specified to match the piping connection. In an ideal situation, end connections and materials between the valve and the piping would be identical; however, this is not always the case.The general rule is that smaller-sized valves—smaller than 2-in (DN 50) valves—can use threaded connections (Fig.4b) while larger sizes—2-in (DN 50) and larger—use flanged connections (Fig.4c and d). The valve body connection may also be welded. Fig. 4a shows a welded connection.



a. b. c. d.

Fig. 4 Valve Body End Connections (Source: Anon., 2004)

2.7 Conditions of Fluid Flow in Pipelines and Restricted Area (Throttling)

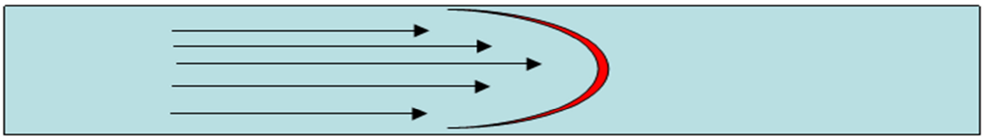


Fig. 5 Laminar Flow (Source: Macdonald, 2008)

At higher velocities high shear forces disturb the fluid flow pattern and the fluid particles start to move in erratic paths, creating turbulent flow. This results in a much flatter flow velocity profile as can be seen in Fig.6. The velocity gradient issmall across the center of the pipe but is high at close proximity to the pipe wall. The opposite is that of laminar (Fig. 5)

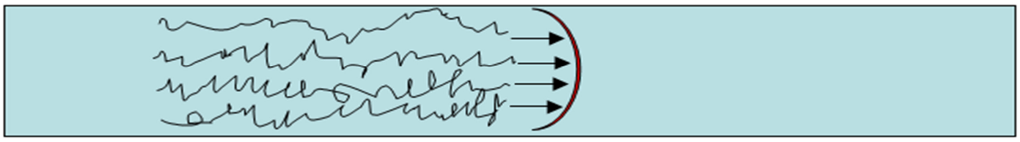


Fig. 6 Turbulent Flow (Source: Macdonald, 2008)

Formation of Vortices

A more drastic change in velocity profile with greater energy losses arises when a fluid passes through a restrictor such as an orifice plate or a control valve opening. Downstream of a restriction there is an abrupt increase in flow area where some of the fluid will be moving relatively slowly. Into this there flows a high velocity jet from the orifice or valve, which will cause strong vortices causing pressure losses and often creating noise if the fluid is a liquid since it is incompressible and cannot absorb the forces.

1.23 Flow Separation

Just after the point where a large increase in flow area occurs the unbalanced forces in the flowing fluid can be sufficiently high to cause the fluid close to the surface of the restricting object to lose all forward motion and even start to flow backwards. This is called the flow separation point and it causes substantial energy losses at the exit of a control valve port. It is these energy losses along with the vortices that contribute much of pressure difference created by a control valve in practice.

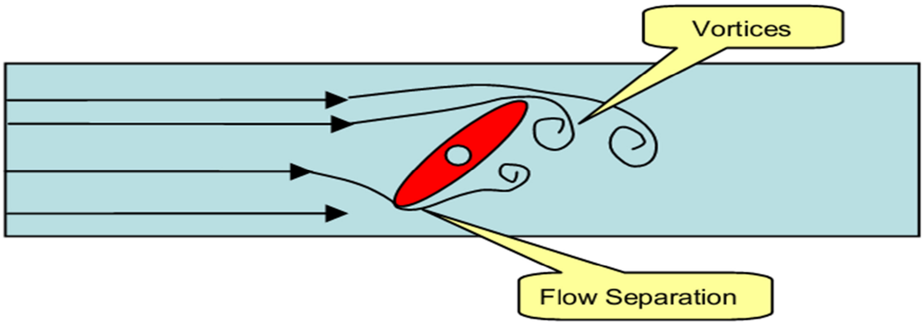


Fig. 7 Vortex Formation and Flow Separation (Source: Macdonald, 2008)

1.24 Flow Pulsation

One of the potential problems caused by vortex formation as described by *Neles Jamesburg* is that if large vortices are formed they can cause excessive pressure losses and disturb the valve capacity. Hence special measures have to be taken in high performance valves to reduce the size of vortices. These involve flow path modifications to shape the flow paths and create “micro vortices”. Understanding fluid dynamics and separation effects contributes to control valve design in high performance applications particularly in high velocity applicationswhen noise and vibration effects become critical.

3 Materials and Methods

3.1 Design of the Foot-operated Device

The design shown in Fig.8 is an assembly of a spring-loaded valve to which a foot actuating device has been attached by means of a control rope to serve as an extension of the actuating element valve.

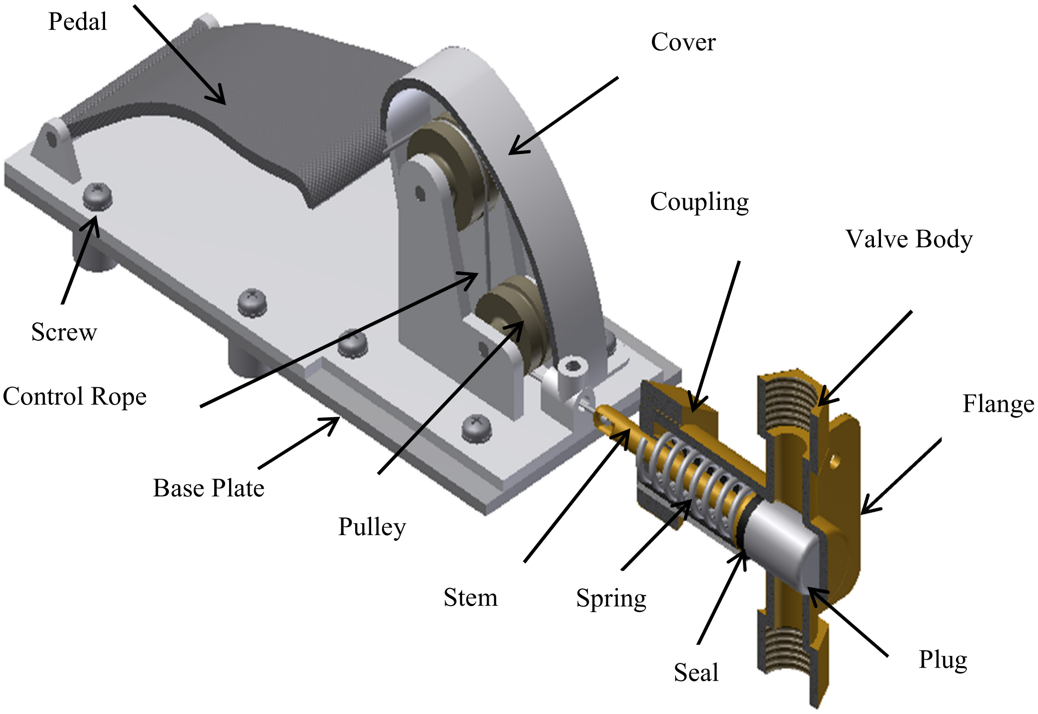


Fig. 8 Sectioned Isometric View of the Device

The valve has a tee-shaped body which houses the closure element (plug) and a compression spring. It has flanges on its sides to help in mounting the valve into the wall in which the pipe lines pass and also bear the load exerted on the valve. This shape was selected so as to allow easy fluid flow through the valve (for on-off application where there is no need for a significant change in inlet and outlet pressure) and to also facilitate easy manufacture and assembly.

The inner geometry of the body, especially the pressure retaining part (the seat) is designed such that the flow passage has smooth walls to prevent formation of vortex which results in turbulence and other irregularities (cavitation and flow pulsation) related to pressure reduction in valve design. The plug diameter is made a little bigger than the inlet diameter of valve so as to ensure effective plug seating (Anon., 2004). This will prevent leakage. The plug is loaded with a spring. This provides the seating force of the plug and returns it when the stem is released after being pulled to open the valve Seals are provided where necessary to prevent leakages. The stem is given an eye at the part that extends outside the coupling (as indicated in Fig.8) in order to accommodate a control rope which serves as the linkage between the valve and actuator.

The second part of the assembly which is the actuator (positioned on and fastened to a base plate mounted on the floor) consists of a foot pedal assembled to the main body of the frame by a pin (located axially using retaining rings) to provide a pivot about which it will swing. The other end of the pedal is attached to the control rope which moves on two pulleys mounted on axels and axially located by the use of retaining rings.

The control rope passes through a cylindrical hole in front of the main body which accommodates headed nut which enables gripping of the rope when screwed. This is to serve as a safety device. It will prevent children from operating the pedal, in so doing misuse of water at home by children is avoided or reduced. The rope attached to the valve is provided an initial tension by the spring in the valve (preload of spring). This is doneby pulling the rope to the point where the stem pulls until a mark on it indicating the right tension is shown, the rope is then fastened.

The cover covers the pulley assembly so as to protect it from dust and spillage of fluid; it is fastened to main body by means of screws. Fig. 9 shows the dimensioned isometric view of the design.

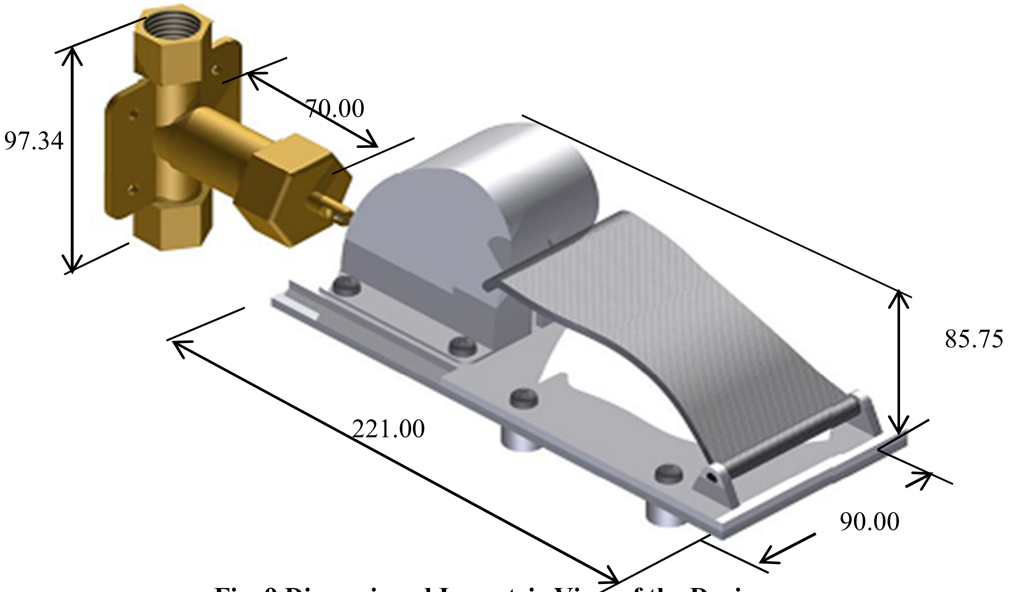


Fig. 9 Dimensioned Isometric View of the Device

3.2 Elements of the Device

The elements forming the device are the main body of valve, plastic lining, plug, seals, stem, and spring, main body of actuator, foot pedal, pulleys, axles, retaining ring, control rope, base plate, cover and screw.

3.3 Principle of Operation of the Device

For the design to be used it must be assembled as shown in Fig. 9 making sure that the correct tension is provided in the control rope. The position of the foot during operation is as indicated in Fig. 10.

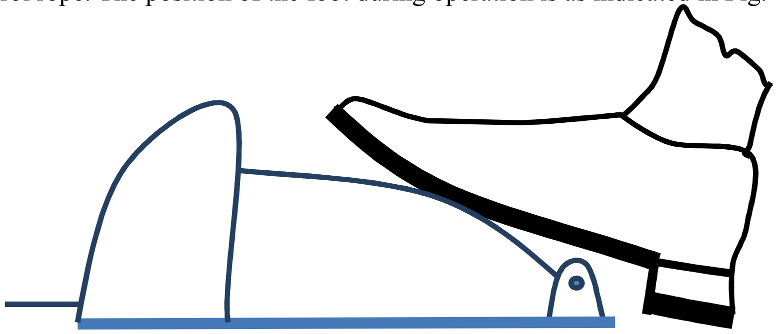


Fig. 10 Position of Foot during Operation of the Pedal

To use this device the operator must step on the pedal as indicated in Fig.10. In that position the required force is applied to the pedal to cause it to swing about its pivot in the clockwise direction. Because the control rope is attached to the pedal it is correspondingly pulled by it through a distance relating to the applied force.

As the rope is being pulled it moves on the pulleys. These pulleys serve as the support and a means to reduce rope wear and losses. As the rope moves it pulls the stem which in turn pulls the plug to open the port allowing the flow of water or fluid through it. The flow rate of the fluid is dependent on the port area made available for fluid to flow through.

After the user of the device has finished he or she removes the foot to release the compressive force on the spring allowing the plug to return into its seat to stop the flow of water through the plumbing fixture being used.

3.4 Elements, Parameters and Materials for the Elements of the Design

All the elements that form the design, the materials of which they are made and the workshop processes used to form some of these elements are indicated below.

3.4.1 Main Body of Valve

The main body of Valve as indicated in Fig.11 is a cast element which houses the plastic lining, the spring, the plug and stem assembly. It has internal threads at the ends (inlet and outlet) to accommodate pipes or nipples. This element is flanged so that this flange will bear the forceon the valve not the tubes connected to the valve. The part of it with external threadscut on it accommodates a coupling that keeps elements assembled in the valve in position. It is made ofbrass alloy. Brass has a wide application, some of which includes the design of plumbing valves and pump casing (Budinski and Budinski, 1999).

Fig. 11 Main Body

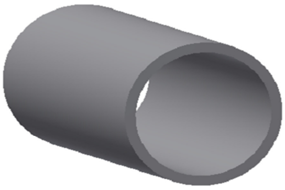


Fig.12 Plastic Lining

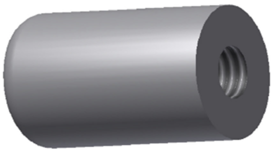


Fig.13 Plug

Fig.14 Seal of the Valve

3.4.2 Plastic Lining

This element, as shown in Fig. 12 is inserted into the body of valve up to where spring is located so as to protect the spring from wear due to sliding against the wall of the valve. It is made of nylon. This plastic has highest melting point, rigidity, and strength (Rollason, 1973).

3.4.3 Plug

The plug (Fig. 3.6) is a machined component threaded at the end of the flatsurface to accommodate the stem. It is made of brass the material of which the valve body is made of.

3.4.4 Seal and Packing

Fig. 14 shows the seal.It is used to prevent internal leakage of the valve when it is closed. Whiles the packing (stem seal) is used to prevent external leakage of fluid. It maintains a clean environment of the valve vicinity. They are made of carbon graphite (Warring, 1982).

3.4.5 Stem

It is formed by casting its blank and finally machinedand threaded to size.It is the part of the plug that extends out of the valve body to take-up the control rope. The stem has threads cut on it so as to accommodate the plug and help secure a seal behind the plug by means of a flanged nut which forms part of the stem (Fig.15). It is made of brass.

Fig.15 Stem

3.4.6 Spring

The spring used is a compressive spring, Fig.16. It provides the seating force of the plug as well as the initial tension (preload of spring) in the control rope.It also returns the plug after compressive force on it is released. The spring is made of music wire. This is the best, toughest, and most widely used of all spring materials for small springs; it has the highest tensile strength and can withstand repeated loading than any other spring material (Budynas and Nisbett, 2011).

Fig.16 Spring

3.4.7 Main Body of the Actuator

This is the element that supports the pulleys and pedal by means of axles. It has a cylindrical tube infront of it through which the control rope passes and serves as a guide to determine as to whether the control rope is in line with the valve or not. Holes are drilled on it so that itcan finally be mounted on a base plate after all other elements are mounted on it. Given in Fig.17is the main body of the actuator.It is made of austenitic stainless steel.This steel is ductile, corrosion resistant and has the highest weldability (Rollason, 1973).

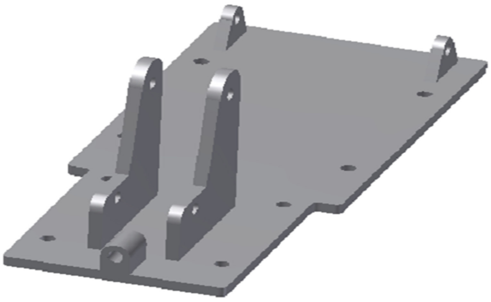


Fig. 17 Main Body of the Actuator

3.4.8 Foot Pedal

The foot pedal (Fig. 18) is an element of the actuator on which the user of a plumbing fixture steps to apply the needed force to actuate the valve. It has a hole through which the control rope passes so as to be linked to the valve through the stem. It is also made of austenitic stainless steel.

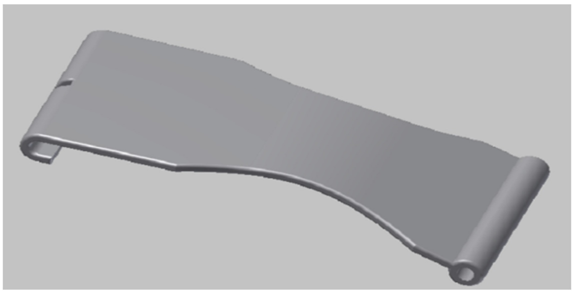


Fig.18 Foot Pedal

3.4.9 Pulley

The pulley (Fig.19) has the shape of a circular disk with a curved base groove of radius(r) around its periphery to guide the control rope. It has hobs projecting on the flats of the disc and a hole in its center through which an axle passes during mounting. It is made of nylon plastic by casting (Neale, 1973). Nylon is wear resistant and a strong engineering plastic.

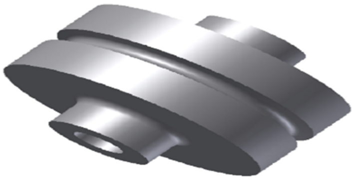


Fig.19 Pulley

3.4.10 Axle

It is a nonrotating cylindrical member which provides a support for both the pedal and pulleys. These three elements, (the two pulleys and the pedal) undergo some oscillatory motion on the axle but not a complete rotation.Theaxle (Fig 20) is made of SAE 1030 CD (Budynas and Nisbett, 2011)

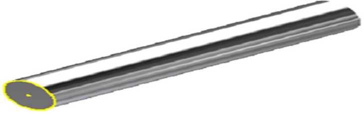


Fig.20 Axle

3.4.11 Retaining Ring (self-locking).

This element locates the axles in a way as to prevent them from dislocating axially. It has a central hole to accommodate the axle and lugson which two small holes are made to accommodate assembly pliers (Parmley, 1985).This element is made of carbon steel; SAE 1060 (Budynas and Nisbett, 2011). The carbon composition of this metal makes it hardenable. The need of the metal to permit hardening is to give the retaining ring some amount of spring property. Fig. 21 shows the retaining ring.

Fig. 21 Retaining Ring

3.4.12 Control Rope

It is a flexible element that links the actuator and the valve;it has 19 strands wound together to form a single rope.The control rope (Fig.22) is attached to the pedal by the use of crimps(as indicated on the control on Fig.22a. and b.) or by other fasteners (especially Fig.22a). This element transfers the force applied on the foot pedal to the stem so as to pull the plug and thereby open the valve. It is made of music wire; hasthe highest tensile strength and can withstand repeated loading (Budynas and Nisbett, 2011).

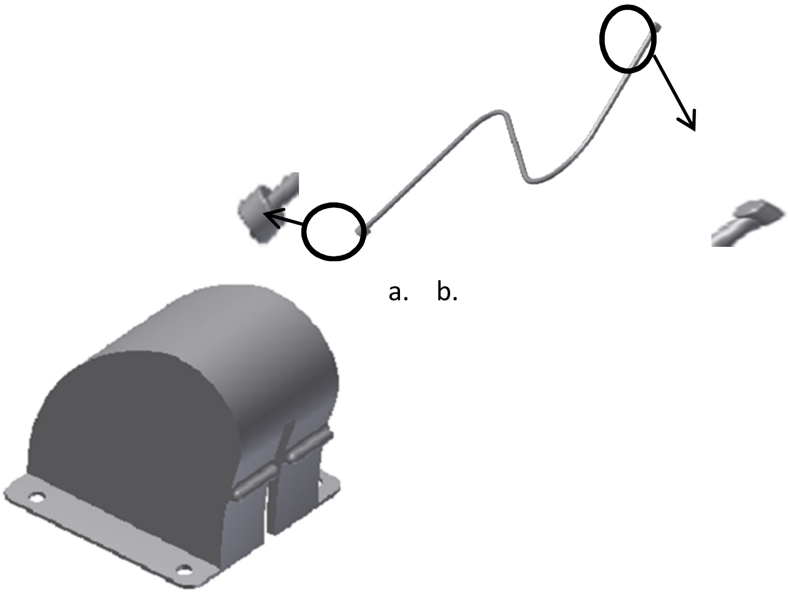


Fig. 22 Control Rope

3.4.13 Base Plate

This element is fixed into the floor so that the whole assembly of the actuator will be mounted on it. It has holes to take up screws. It is made of austenitic stainless steel; highly resistant to corrosion (Rollason, 1973).

3.4.14 Cover of the Pulley Assembly.

Indicated in Fig. 23 is the cover of the pulley assembly. Its curvature is to ensure that any spill of water on it will easily flow. It has holes to accommodate screws to the actuator-frame and a stopper which prevents the pedal from moving a distance beyond that needed for full port opening. It was fabricated by forming of developed surface and welding. It is made of austenitic stainless steel. This metal was used because of its high weldability and corrosion resistance (Rollason, 1973).

Fig.23 Cover of the Pulley Assembly

3.4.15 Screw

The screw is used to fasten the cover onto the actuator-frame and both to the base plate. It is made of medium carbon steel. This steel has good formability; it is ductile and has relative good strength. Medium carbon steel (C=0.25-0.55 %) is used for rolls, axles, screws, cylinders and crankshafts (Rollason, 1973).

4 Design Calculations and Results

4.1 Introduction

The design calculation covers analysis on the design of the actuating mechanism. This covers, the design of the spring, selection of control rope and pulleys, tensions in control rope and the action of reactions due to tensions in the control ropes on the axles supporting the pulley

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4.2 Consideration of Overall Free Body Diagram of Design

The overall free body diagram of the design (Fig 24.) presented at this section covers the outline of the links that come together to form the proposed design.It provides an insight into the action of some of the forces in the linkage during operation.

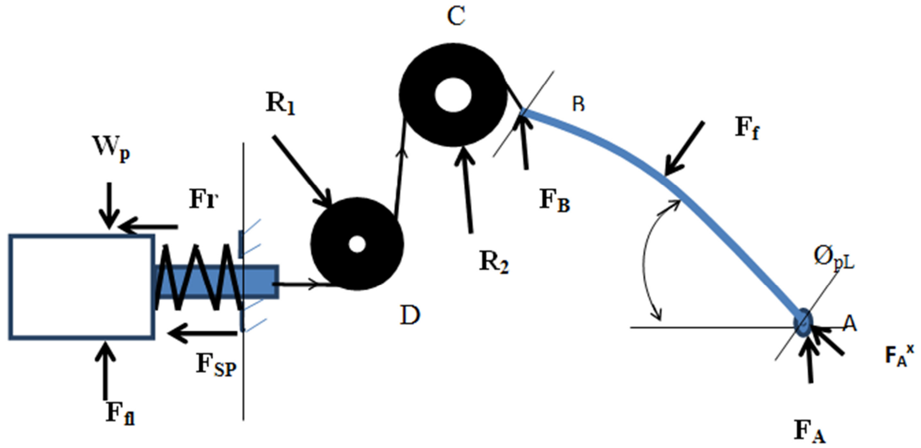

Fig. 24 Overall Free Body Diagram of the Design

The parameters indicated on Fig.24. are as follows:

F_{fL} is the force due to the pressure of the fluid against plug.
Wp is the force due to the weight of the plug
$F_r$is the frictional force
F_{SP} spring force (reaction)
R_1 reaction due to axle supporting pulley 1 at D
R_2 reaction due to axle supporting pulley 2 at C
F_B force at point B
F_F force applied by foot
F_A^y support reaction at point A in the y direction
F_A^x support reaction at point A in the x direction

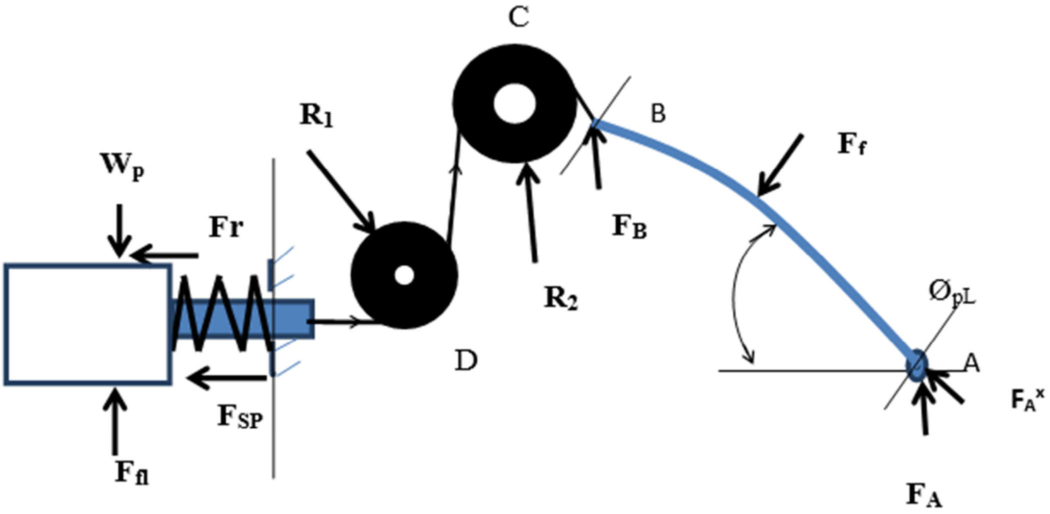

Fig. 24 Overall Free Body Diagram of the Design

Assumptions made:

- The force exerted on the plug due to fluid pressure (**F_{fl}**) is neglected. This is because the flow under normal conditions especially where water distribution is by gravity is of low pressure and has no significant effect on valve.
- Force due to the weight of the plug (**W_p**) is negligible. This is because it is small and hollow.
- Force due to friction is neglected. This is because the normal force (**$F_{fl} - W_p$**) on which this force depends is negligible. Moreover the speed at which mechanism is operated is small.

4.3 Design of the Spring

Information presented under this section on the design of the helical compressive spring that was used in the device was based on the approach used in (Budynas and Nisbett, 2011). All unreferenced expressions used are therefore referenced to these authors.

Spring type**:** Helical compression spring (unpeened)

Spring Failure:

- Shear (torsional and direct shear)
- Buckling (excessive deflection)

Spring Material: The spring is made of music wire.

Modulus of elasticity (E):196.5 GPa (Budynas and Nisbett, 2011)

Torsional modulus of elasticity (G):81.0 GPa (Budynas and Nisbett, 2011)

The spring considered in this project is squared and ground, and preloaded with a static force (**F_{min}**) and a maximum dynamic force of (**F_{max}**). Spring design considerations are for fatigue loading (service is for dynamic purposes). Fig.25 indicates the deformation undergone by spring during preloading and loading at full port.

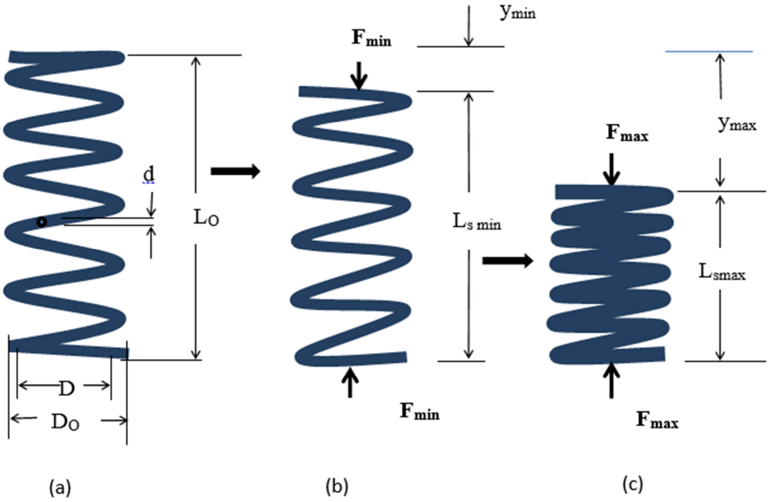

Fig. 25 Deformation Undergone by Spring during Preloading and Loading at Full Port

The unknown parameters indicated in Fig 25 are as follows:
d is spring wire diameter; D_O is the outer diameter of spring; D is the mean diameter of spring; y is the deflection of the spring; L_O is the free length ofthe spring; L_S is the solid length of the spring; F_{min} is the minimum compressive force; F_{max} is the maximum compressive force; min denotes preload conditions; max denotes maximum loading conditions
NB. Spring was designed for full port condition (maximum loading)

4.3.1 Design Calculations onSpring for Fatigue Loading

Known spring parameters are as follows

d =1.8 mm; D_o = 18.3 mm; D = 16.5 mm; $y_{min} = 2 \text{ mm}$; $y_{max} = 17 \text{ mm}$; $L_s = 26.5 \text{ mm}$

Lo = 43.5 mm $F_{min} = 4.616 \text{ N}$; Spring constant (k) = $\frac{F_{max}}{y_{max}}$ (1)

$$Fa = \frac{F_{max} - F_{min}}{2} \qquad k = \frac{39.24}{17} = 2.308 \text{ N/mm} \quad (2)$$

$$F_a = \frac{39.24 - 4.616}{2} = 17.312 \text{N} \qquad F_m = \frac{F_{max} + F_{min}}{2} \quad (3)$$

where, F_a is the amplitude force.

$$F_m = \frac{39.24 + 4.616}{2} = 21.928 \text{ N}, \quad S_{ut} = \frac{A}{d^m} \quad (4)$$

where, F_m is the midrange force,

where,

A and m are constants S_{ut} is the ultimate shear stress A= 2211 MPa mm^m; m = 0.145

$$S_{ut} = \frac{2211}{1.8^{0.145}} = 2030.366 \text{ MPa}$$

For an unpeened spring: Amplitudestrength, $S_{sa} = 241 \text{MPa}$

Midrange shear strength, $S_{sm} = 379$ MPa

Shearing ultimatestrength, $S_{su} = 0.67 S_{ut} = 0.65 \times 2030.366 = 1319.738 \text{MPa}$ $\quad S_{sy} = 0.45 S_{ut}$ (6)

where, S_{sy} is the yield shear strength

$$S_{sy} = 0.45 \times 2030.366 = 913.665 \text{ MPa}$$

$$(K_B) = \frac{4C + 2}{4C - 3}$$

$$C = \frac{D}{d} \quad (4.8)$$

where,

K_B is the Bergstrasser factor
C is the coil curvature

$$C = \frac{16.5}{1.8} = 9.167$$

$$K_B = \frac{4(9.167) + 2}{4(9.167) - 3} = 1.149$$

$$\tau_a = K_B \frac{8 F_a D}{\pi d^3} \quad (4.9)$$

where,

K_B Bergstrasser factor

τ_a is the amplitude shear stress

$$\tau_a = 1.149 \times \frac{8 \times 17.31 \times 16.5}{\pi \times 1.8^3}$$

$$= 143.293 \text{ MPa}$$

$$n_f = \frac{S_{sa}}{\tau_a} \quad (4.10)$$

where,

n_f is the fatigue factor of safety

S_{sa} is the amplitude shear strength

$$= \frac{241}{143.293}$$

$$= 1.682$$

$$\text{Closure force } (F_s) = (1+\xi) F_{max} \quad (4.11)$$

where,

$\xi = 0.15$(ensures robust design of spring)

F_S is the closure force

$$F_S = (1 + 0.15) \times 39.24$$

= 45.126 N

This is theforce at the point where the coils of the spring are in contact under maximum load.

Condition for maximum permissible operating force

$$F_{max} \leq \frac{7}{8} F_s \qquad (4.12)$$

Considering L.H.S of the expression,

$$\frac{7}{8} F_s = \frac{7 \times 45.126}{8}$$

$$\mathbf{F_s} = 39.485 \text{ N}$$

Since condition for maximum permissible load is satisfied, $\mathbf{F_{max}}$ is permitted.

$$\tau_s = \tau_a \frac{F_s}{F_a} \quad (4.13)$$

where,

τ_s is the shear stress at closure

$$\tau_s = 143.293 \times \frac{39.485}{17.31}$$

$$= 326.859 \text{ MPa}$$

$$n_s = \frac{S_{sy}}{\tau_s} \quad (4.14)$$

where,

n_s is the factor of safety at closure

$$= \frac{913.665}{326.859}$$

$$= 2.8$$

Allowed free length of the spring considering closure force (F_S)

$$L_O = L_S + \frac{F_S}{k} \qquad (4.15)$$

$$= 26.5 + \frac{39.485}{2.308}$$

$$= 43.608\,\text{mm}$$

For absolute stability of spring:

$$L_O < \frac{\pi D}{\alpha}\left(\frac{2(E-G)}{2G+E}\right)^{\frac{1}{2}} \qquad (4.16)$$

Considering R.H.S of expression (4.16)

$$\frac{\pi D}{\alpha}\left(\frac{2(E-G)}{2G+E}\right)^{\frac{1}{2}} = \frac{\pi \times 16.5}{0.5}\left(\frac{2(196.5-81.0)}{2\times 81+196.5}\right)^{\frac{1}{2}}$$

$$= 83.22\,\text{mm}$$

Since $L_O < 83.22$ mm the spring is stable.

4.4 Calculation on the Selected Control Cable and Pulley Sizing.

The information provided here looks at how the parameters of these elements affect each other (Table.4.1).Tension considerations are made based on the maximum input force needed to open vale to full port.

4.4.1 Pulley Size and Cable Fatigue.

Material for pulley: Nylon

The cable selected conforms to the pulley geometry (Fig.26) selected. The other parameters (hob diameter and height, and width of pulley) are solely based on the designer. It depends on the spacing provided for the pulley. Fig.26 shows the geometry of the pulley.

Table 4.1 Shows the Effect of Fatigue Life on Varying (D/d)

D/d	Cycles to failure
20	56 000
25	170 000
30	330 000
37.5	after 650 000 no failure

(Source: Neale, 1973)

Fatigue life of rope = $\frac{D}{d}$ (4.17)

where,

D is the pulley diameter over groove
d is the cable diameter inclusive of thermoplastic covering

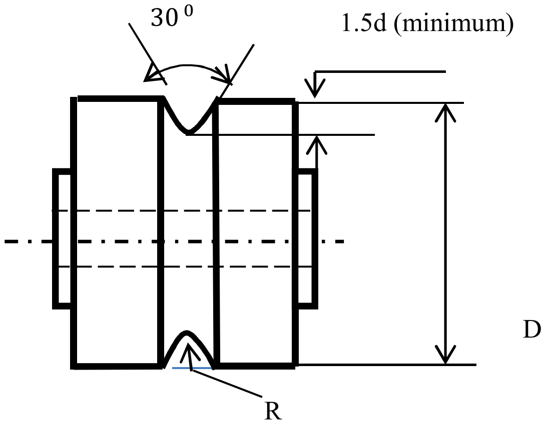

Fig. 26 Geometry of Pulley (Modified after: Neale, 1973)

The parameters on Fig.4.5 are:

R = 0.53d
R = 0.811 mm
d = 1.53

Fatigue life of rope considering pulley 1 of diameter $(D_1) = \frac{26}{1.53}$

= 17

The fatigue life of the rope with reference to pulley 1 is low (below the minimum life cycle of.56 000), this is tolerated because of low load application of rope and a reduction in the wrap angle ($Ø_1$) so as to avoid excessive rope bending.

$$\text{Life in years} = \frac{56\,000}{24(366)} = 6.38 \text{ years}$$

Fatigue life of rope considering pulley 2 of diameter $(D_2) = \frac{37.5}{1.53}$

$D_2 = 25$

From Table 4.1 it can be seen that the fatigue life of the rope with reference to pulley 2 is 170 000 cycles

$$= \frac{170\,000}{24(366)}$$

$$= 19.35 \text{ years}$$

The condition for selecting pulley diameter is such that D must not be less than 35d.

Compromise has been made because of low load application and the spacing intended to accommodate design during mounting. This brought about the need to reduce the wrap angles in order to decrease bending of rope.

4.4.2 Control Rope

Material: Music wire
Strand construction: 19 wires; single wire section Overall diameter (d) = 1.53 mm
Minimum breaking load of rope = 2220 N Recommended maximum input load = 220 N
(Neale, 1973)

Control Rope Tension Calculation

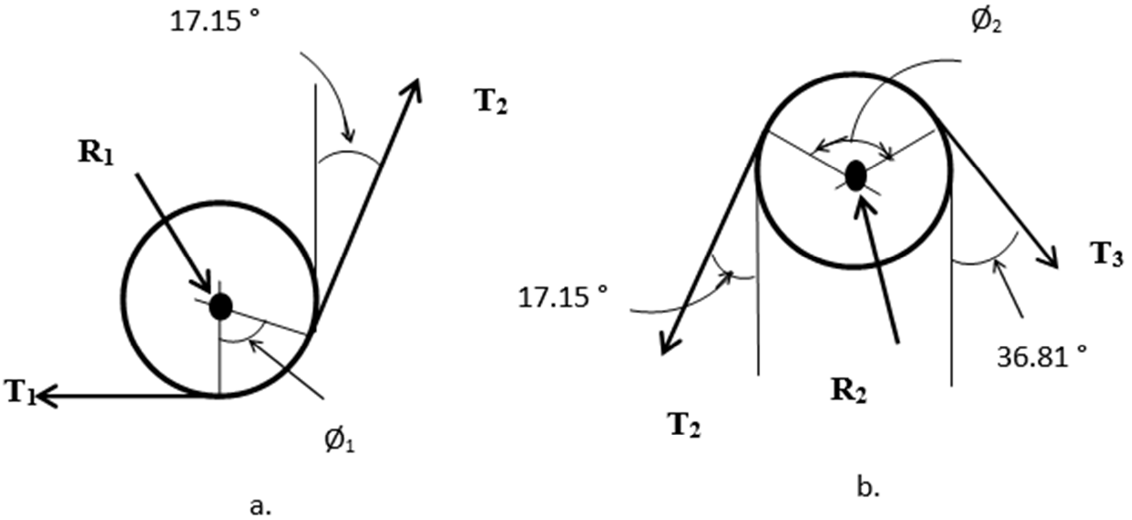

Fig. 4ppp.F4 TefF27nsions Ff Control Ropes and the Reactions Due to the Axles

From Fig.27 a and b
Wrap angle of pulley 1 ($Ø_1$) = 72.86° (1.272 rad)
Wrap angle of pulley 2 ($Ø_2$) = [94.35 °(1.647 rad)and 129.41 °(2.259rad)angle before pedal is activated and angle at maximum operation of pedal respectively]
Considering tensions in control ropeat maximum pedal loading

$$2.3\log\left(\frac{T_1}{T_2}\right)=\mu\phi$$ (Khurmi and Gupta, 2005) (4.18)

where,
μ is the coefficient of dynamic friction between rope and pulley = 0.15 (Anon., 2013)
Ø is the wrap angle in radians
$\mathbf{T_1}$and $\mathbf{T_2}$ are tensile forces in the control rope
Considering pulley 1 as shown in Fig.27 a

$$T_1 = 39.24\ \text{N(maximum force needed to compress spring to solid length at full port)}$$

$$\log\left(\frac{39.24}{T_2}\right)=\frac{0.15\times1.272}{2.3}$$

$$T_2 = 32.417\ \text{N}$$

$$2.3\log\left(\frac{T_2}{T_3}\right)=\mu\phi$$ (Khurmi and Gupta, 2005) (4.19)

where,

$\mathbf{T_2}$ and $\mathbf{T_3}$are tensile forces in a portion of the control rope as indicated in Fig. 27d

$$\log\left(\frac{32.417}{T_3}\right)=\frac{0.15\times2.259}{2.3}$$

$$T_3 = 23.091\text{N}$$

The tensions calculated fall within the recommended range of control rope parameters as indicated earlier.

4.5 Retaining Ring and Axle Selection

The retaining ring selected defines the diameter of the shaft or axle as well as the material strength.
Given parameters of retaining ring:
Range of shaft or axle diameter = 2.388 mm - 9.525 mm
Minimum tensile strength of shaft or axle material = 1.0335 MPa

Minimum thickness of retaining ring = 0.254 mm (Parmley, 1985)
Selected parameters of retaining ring:
Selected diameter of axle (inner diameter of retaining ring) = 5 mm
Material/Finish: SAE 1060 (hardening; to develop spring properties of retaining ring).
Tensile strength of selected material: 680 MPa.
Yield strength: 370 MPa. Selected ring thickness = 0.5 mm
(Budynas and Nysbett, 2011) and (Parmley, 1985).
Axle parameters:
Material: SAE 1030 CD Yield Strength: 440 MPa Tensile Strength: 520 MPa
(Budynas and Nysbett, 2011) and (Parmley, 1985).

5. Discussions

5.1 Input Force on Pedal

The position of the pedal is for full port condition. That is, the pedal is considered for maximum loading, it is considered as a straight member.The analysis made here is for the determination of the input force on the pedal (Fig. 28).

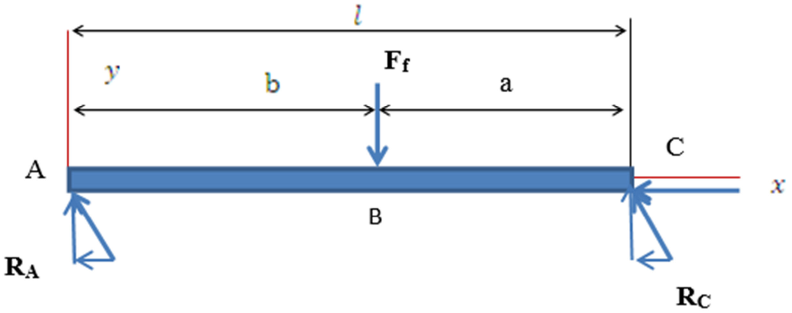

Fig.28 Loading of Pedal

$R_A = T_3 = 23.091$ N
$l = 118.777$ mm (projected length of pedal)
$a = 58.206$ mm (distance from pedal support to point of application of foot force)
Angle of inclination of $\mathbf{R_A}$ and $\mathbf{R_C}$ are same and equal to angle of inclination of $\mathbf{T_3}$ which is 38.37°
Taking moments about C

$$\sum M_C = 0$$

$$-R_A \cos\phi_{RA} \times l + F_f \times a = 0 \qquad (4.20)$$

$$-23.091 \cos 38.37 \times 118.777 + F_f \times 58.206 = 0$$

$$F_f = 36.208\ \text{N}$$ (Input force on pedal)

6 Conclusion and Recommendations

6.1 Conclusion

A device to serve as an alternative means of water flow control into plumbing fixtures to get rid of problems of contamination associated with the use of the manual control valve which can easily be assembled and installed without difficulty, has been designed. The size and shape have been designed, and other mechanisms selected to enhance its ergonomics.The maximum input force accommodated by the actuator in order to open the valve at full port is 36 N for users of ages of 15 years and above.

6.2 Recommendations

It is recommended that:

- Software for fluid flow analysis must be usedto analyze the behavior of the valve under standard flow parameters and the necessary action taken to correct any irregularities that may arise due to inappropriate flow path geometry and dimensions used.
- Standards covering the design of valves must be looked into in other to appropriately specify the valve geometry.
- Selection of the right pipes, pipe joints and couplings must be selected when plumbing works are being carried out in order to ensure sanity in the vicinity of the device and the fluid being handled.

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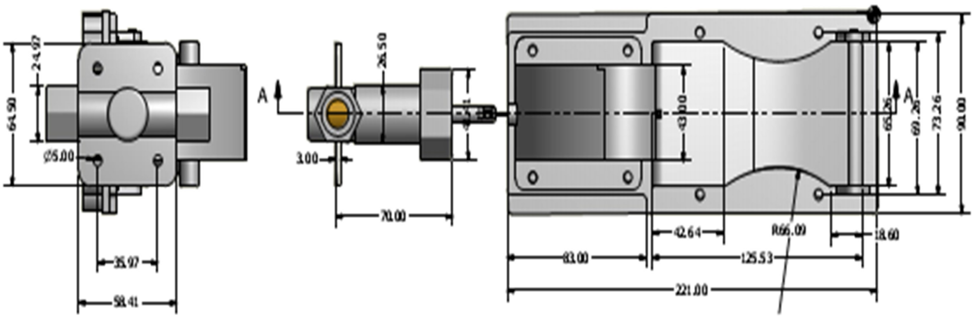
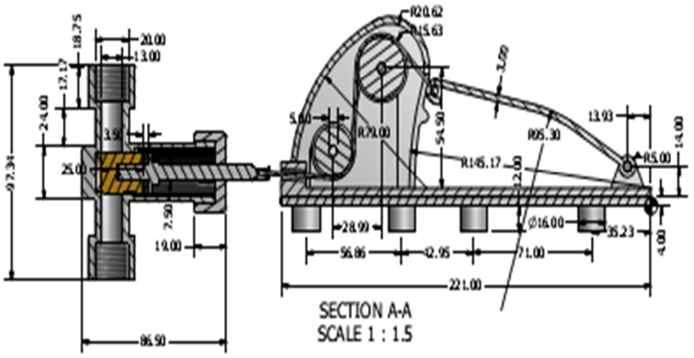
Appendix

Detail Drawings of the Proposed Design





NB.
All dimensions in mm.