Mathematical Geometric of Open and Close Valve in Water Hammer

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Abstract: A valve is a device used to control the flow of the fluid. The control is achieved by closing, opening or partially obstructing various passageways. Valves have many applications and the valves are considered to be pipe fittings, and there are many different valve designs. Each of the many different valve designs has its own advantages and disadvantages. For example, the gate valve slides up and down like a gate, the globe valve closes a hole placed in the valve, the angle valve is a globe valve with a 90° turn, and the check valve allows the fluid to flow only in one direction. In this paper, the present investigation is to explore the effect open and close valve on water hammer and study the valve types with equations for every valve, the results give information about the pattern of valve closing and valve opening crescent water hammer.

Keywords: closing valve, Water Hammer, valve, closing law, open closing, pressure wave, transitory.

1. Introduction

A valve is a machine or tool that regulates the flow of materials, and usually contains one or more moving parts that are capable of opening and closing or obstructing the flow of a fluid (oil, gas, water), and is operated mechanically, electrically, or hydraulically by liquid or air. Valves with pipes connected to the valve. They are mechanical tools that can control, intercept and completely isolate the flow in pipes. Valves are available in many types and shapes**. [1]**

The water-hammer has its a pathological disorder that results from hydraulic systems. The operation of a valve makes a transitory in the hydrodynamic system that products variations on the flow conditions. These variations are experiential in the ondulatory performance that shows the pressure and the fluid speed, an alternative succession of crests and mangers that attenuates in time. This passing is known as water-hammer. The previous studies on the water-hammer phenomena have been found in the works of Young (1808) **[2**], Wertheim (1848) **[3]** and Michaud (1878) **[4]** among others. Joukowsky (1900, 1904) **[5.6**] printed the results of the new studies carried out on the water system delivery of Moscow. In that work it was protracted the transitory account to the total time of period. Established a rational appearance for the complex variations of compression that experiences a tube net taking into account the replication and broadcast in pipe boundaries, and introduced the tube period concept. These the whole thing were based on the comments and growths of Wertheim (1848), von Helmholtz (1847) **[7],** Korteweg (1878) **[8]** and Lamb (1898) **[9].** During that period (1903-1913) Lorenzo Allievi **[10]** was an active detective in this theme, inward to the same results as Joukowsky, assuming tube flow deprived of resistance, uniform section, homogeneous wall and uniform delivery of speed of the fluid.

Allievi has developed the wave equations, rejecting the convective terms and solving it by the general method proposed by Riemann and D'Alembert. Allievi (1925) has extended the Joukowsky results to the cases of non-instantaneous valve closing, that is to say, closing times higher than the pipe period being pressure differences are on the whole tube not just on the beginning of the valve (Murga and Molina;

1997) **[11**]. Wood (1938) **[12]** only he was able to provide a solution for closure laws in a simple pipe model. Rich (1945) **[13]** proposed the use of the Laplace-Mellin transform for the same system. With the advancement in computing technology appeared the firsts numeric methods for the Water hammer modeling (Harding, 1966) **[14**]. The Method of the Characteristics is a particularly appropriate technique for the solution of hyperbolic partial differential equations study (Abbott, 1966) **[15].** Gray (1953, 1954) **[16],** Ezekial and Paynter (1957) and Streeter et al**. [17,18]** (1962, 1967, 1972, 1983) have found useful the use of this technique.

In Europe, Fox (1968) **[19],** Evangelisti (1969) and Swaffield (1970) **[20]** were the precursors in the use of this method, which has settled down as a standard technique for the transitory analysis (Brunone et al., 1991) **[21].** Some authors have indicated the influence of the closing perturbation on the pressure wave transient, however the closing functions that have been included in successive works in models of the Water-hammer are restricted to the instantaneous, the lineal and the cosenoidal closing (Hager, 2001). **[22]**

2. Type of Valves: There are many types of valves that have been developed depending on the different types of fluids and the way the valves work in them. Examples of the common types are the globe valve, gate valve, ball valve, plug valve, butterfly valve, diaphragm valve, check valve, pinch valve, and safety valve. Each valve has characteristics that different from the other valve, and each valve has advantages and disadvantages, so the valves are designed according to the work in them, so some of them work are capable of throttling flow, other valve types can only stop flow, others work well in corrosive systems, and others handle high pressure fluids. Each valve type has certain inherent advantages and disadvantages. Understanding these differences and how they effect the valve's application or operation is necessary for the successful operation of a facility. **[23]**

- **Globe valve:** It operates by responding action of disc or plug. The disc or plug moves to or away from the seat thereby stopping the fluid flow or allowing the fluid to flow. The disc or plug seats over the valve seat. The valve seat can be removable. Pressure drop in the globe valve is high. the valve can be manually operated or power actuated or automatic actuated**.**

  The Actuation Function:

$$\eta = 1 - \frac{t}{T_v} \qquad (1)$$

$$\eta = 1 - [\frac{t}{T_v}]^2 \Longrightarrow \eta = \theta_m \left[\frac{t}{T_v}\right] \Longrightarrow \eta = \theta_m - [\frac{t}{T_v}]^2 \qquad (2)$$

Where T_v is valve actuation time , and θ_m complete actuation angle .

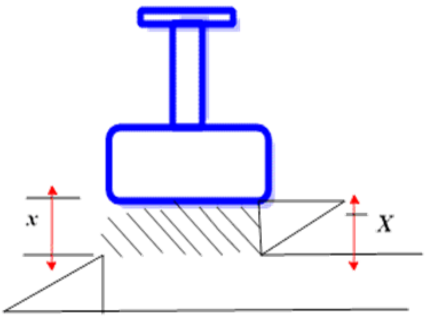

Figure 1: Schematic Representation of Globe Valve

- **Square Gate valve:** It is type of gate valve the valve has a disc (or agate)**,** the gate has a transverse motion in the direction of fluid flow, thus this arrangement either fully stops or opens the passage of fluid. The` valve use of high pressures and temperatures and can use the valve for wide range of fluids.

The Actuation Function:

$$\text{Square Gate} = 1 - \frac{1}{\pi}\left(arccos(2\eta - 1) - (2\eta - 1)\sqrt{1-(2\eta-1)^2}\right) \qquad (3)$$

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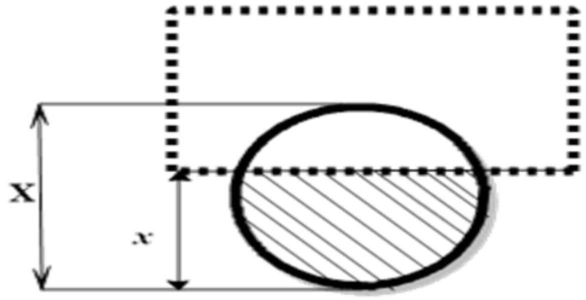

Figure 2: Schematic Representation of Square Gate Valve

- **Ball Valve:** Ball valve has a spherical plug. The spherical plug is a controlling element. they are widely used in chemical process industries. It is used where throttling and shut off combination is required. It offers good flow characteristics. Ball valve consists of a two-way globe and the ball rotates between resilient seats.

The Actuation Function:

$$\text{Ball valve} = 1 - \cos\left(\frac{\pi}{2} - \eta\right) \qquad (4)$$

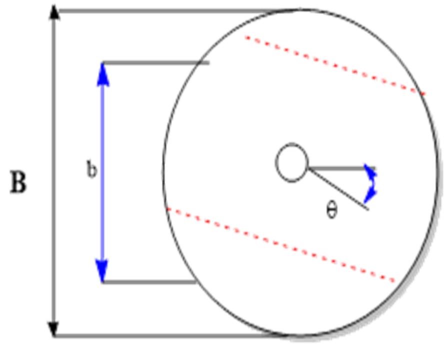

Figure 3: Schematic Representation of Ball Valve

- **Butterfly valve**: In butterfly valve the controlling element is a disc called as blade, vane or flapper, which rotates in horizontal or vertical direction and allows the fluid to flow. Butterfly valve is suitable for throttling or on-off operation at low pressure drop. It is economic, easy to install and does not allow the solids to build up. Butterfly valve can be either screw type or of wafer type. Its operation can be manual, power, or automatic Water type butterfly valve is shown. Butterfly value can be used for vacuum operations or pressures.

The Actuation Function:

$$\text{Butterfly valve} = \frac{1+\cos(\eta)}{2} + \frac{\cos(\eta)}{\pi}\left(\arcsin(-x) + \frac{1}{2}\sin(2\arcsin(-x))\right) - \frac{1}{\pi}\left(\arcsin(x) + \frac{1}{2}\sin(2\,arcsin(x))\right) \qquad (5)$$

Where $x = \frac{sin(\eta)\sqrt{(\frac{B}{b})^2-1}}{1+cos(\eta)}$, $\eta = \theta_m - [\frac{t}{T_v}]^2$

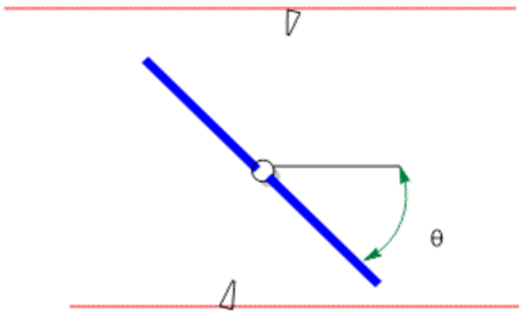

Figure 4: Schematic Representation of Butterfly Valve

- **Needle valve:** Needle Valves are used to meter fluid flow through tubing or ports. Flow is regulated by inserting or withdrawing a tapered stem into or out of a similarly tapered orifice, creating a very precise way of adjusting fluid flow through the orifice. Key specifications include valve type, port connections, valve size, and the materials that make up the valve body, which includes its seat, seal, lining, and stem packing. Needle valves are used in vacuum systems and for metering systems where precise flow regulation is required. Because of the high number of turns required to close a needle valve, they are not ideally suited for use in shut- off service applications.

  The Actuation Function:

  Needle valve $= 2\eta - \eta^2$, where $\eta = \theta_m - [\frac{t}{T_v}]^2$

  hence, Needle valve $= 2(\theta_m - [\frac{t}{T_v}]^2 - [\theta_m - \left[[\frac{t}{T}]^2\right]^2)$ (6)

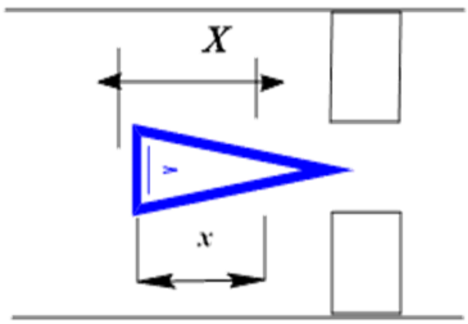

Figure 5: Schematic Representation of Needle Valve

- **Circular Gate Valve:** It is one of Gate valve type and it is one of the original valve designs are ideally suited for on and off, this valve works by lifting a circular gate out of the fluid path when the valve is fully open and the valve is full bore, meaning there is nothing to obstruct the flow because the gate and pipeling. This bore dimeter also determines the valve size

  The Actuation Function:

  Circular valve=$1 - \frac{2}{\pi}(arccos(\eta) - \eta\sqrt{1-\eta^2})$ (7)

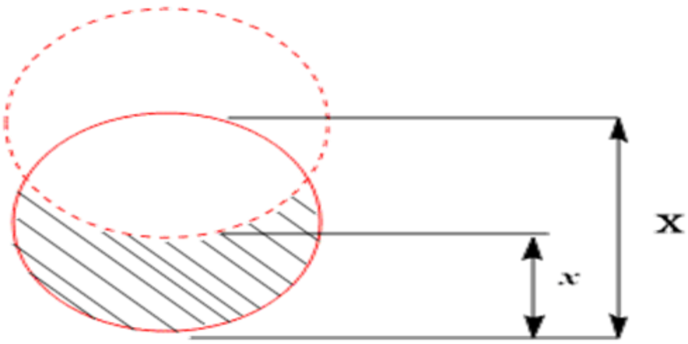

Figure 6: Schematic Representation of Circular Gate Valve

3-Effect Open and Close of Valve on Water Hammer:

Water hammer is a liquid shock wave resulting from the sudden starting or stopping of flow. It is affected by the initial system pressure, the density of the fluid, the speed of sound in the fluid, the elasticity of the fluid and pipe, the change in velocity of the fluid, the diameter and thickness of the pipe, and the valve operating time**.**

The effect of closing the valve suddenly leads to disturbances in pressure, which leads to the occurrence of a pressure wave on the walls of the pipe with increasing the speed of water flow inside the pipe, which leads to the occurrence of water hammer. **[24,25]**

According to Provenzano et al. **[26],** there are four methods which can be used to modify the action of the valve (closure law), most commonly referred to as convex, concave, linear and instantaneous closing law. These types of closing valve laws represent a mathematical function that describes the speed variation of the flow as it is closing. These types of valve closure depend on the rate at which valves can be closed. The valve closure rate plays an important role in controlling the water hammer phenomenon **[27].** In addition, Elaoud and Hadj-Ta¨ıeb **[28]** studied the transient flow in hydrogen natural gas mixture. Studies on such problems are important because hydrogen is usually transported in the same pipeline as natural gas to reduce transportation cost and hydrogen is often stored together with natural gas to enhance its storage capability. However, they seemed to have considered only the linear closing valve to determine the relationship between the mass ratio of mixture and pressure **[29].**

In this paper, the present investigation is to explore the effect open and close valve on water hammer and study the valve types with equations for every valve, Moreover, we develop the code in Matlab program to describe it,

4-. Results and Discussion

analytical graphs of the results obtained for the axial velocity V(t), V_T flow liquid of closing, and wave speed, effect of the density liquid of the pipe . For various values of the m of closing and opening valve, the angle π shift appears between the upstream and downstream pressure waves that travel across the pipe.

The code in MATLAB programing used to obtaine analytical study results. The different parameters used the value pipe radius = 0 · 1 . 0 · 15 with different m values = 0.05<m<32.

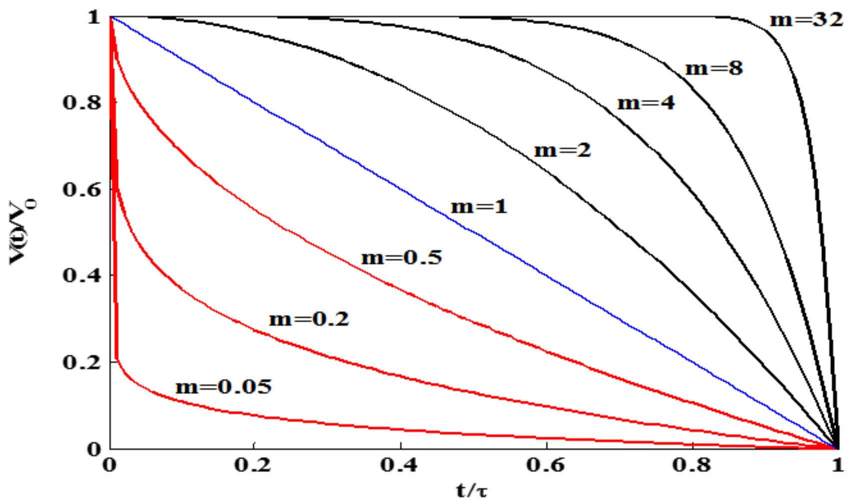

Figure 7: Closing laws corresponding to different m values

In figure (7) The drawing shows the condition of closing and opening the valve during the occurrence of water hammer. form us, it indicates the closing function depending on the value of v=1 and continuing with an increase in the value (V)depending on the time (t) of occurrence of the closing. depended on the closing function

$V(t) = (V_0 - V_T)\left[1 - (\frac{t}{T})^m\right] + V_T$ ·

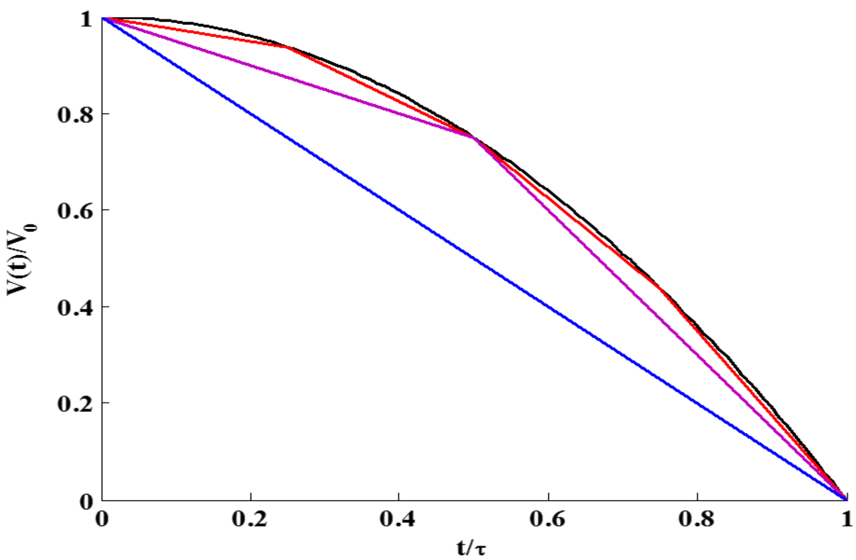

Figure 8: Convex closing

In figure (8) shows a convex closing function in depended the m exponent in Eq

$V(t) = (V_0 - V_T)\,[1 - (\frac{t}{T})^m] + V_T$ And Eq $V_i = (V_0 - V_T)\,[1 - \left(\frac{i\beta}{T}\right)^m\Big] + V_T$,

Determines the closing curve law at true closing law when:

$m = 0$ instantaneous closing, $0 \leq m < 1$ concave closing, $m = 1$ lineal closing, $1 \leq m < \infty$ convex closing.

In figure (9), (10) Valve uniform and accelerated closures are shown respectively. For both closure functions, the circular gate valve flow area gradient evolves slowly during the first 50 % of closure before increasing, whereas the flow area gradient for a ball valve is important during the first 50 % of closure before decreasing. Uniform closure of a globe valve is characterized by a constant gradient

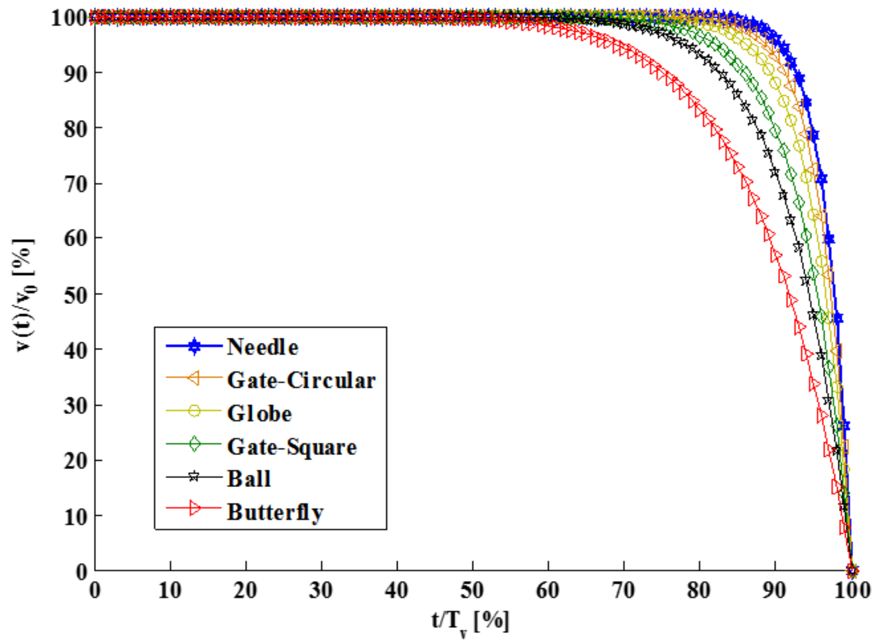

Figure 9: Flow Velocity Across Valve During Accelerated Closure

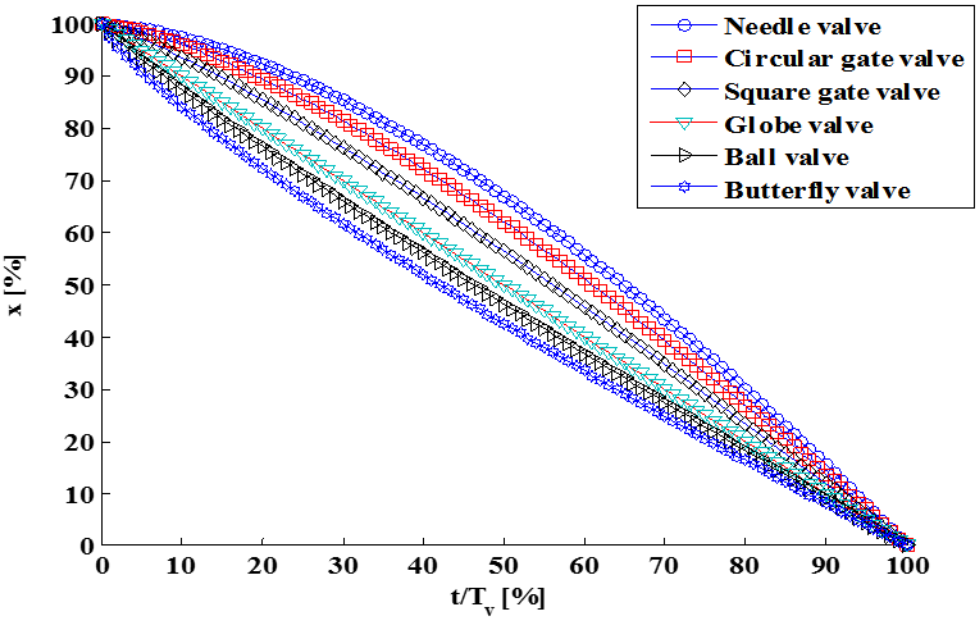

Figure 10: Valve Position During Uniform Closure

In figure (11) the fluid velocity reductions for uniform closure of the six valves considered are shown the fluid velocity reduces slowly until 80 % of the fluid initial velocity, the fluid velocity then decreases rapidly until full closure. The fluid velocity reaches 80 % of the initial velocity at 87 %, 81 %, 76 %, 71 %, 65 % and 55 % of the actuation time for needle, circular gate, globe, square gate, ball and butterfly valves, respectively.

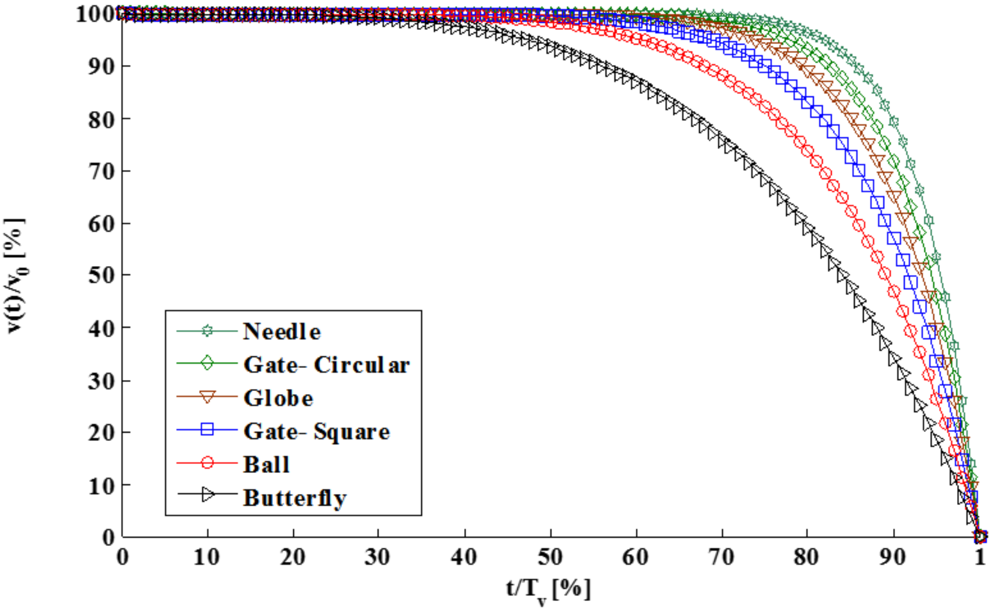

Figure 11: Flow Velocity Across Valve During Uniform Closure

In figure (12) Fluid velocity reductions for accelerated closure of the six valves, the fluid velocity reduces slowly until 80 % of the fluid initial velocity, the fluid velocity then decreases rapidly until full closure. The fluid velocity reaches 80 % of the initial velocity at 93 %, 90 %, 87 %, 81 %, 80 % and 74 % of the actuation time for needle, circular gate, globe, square gate, ball and butterfly valves, respectively.

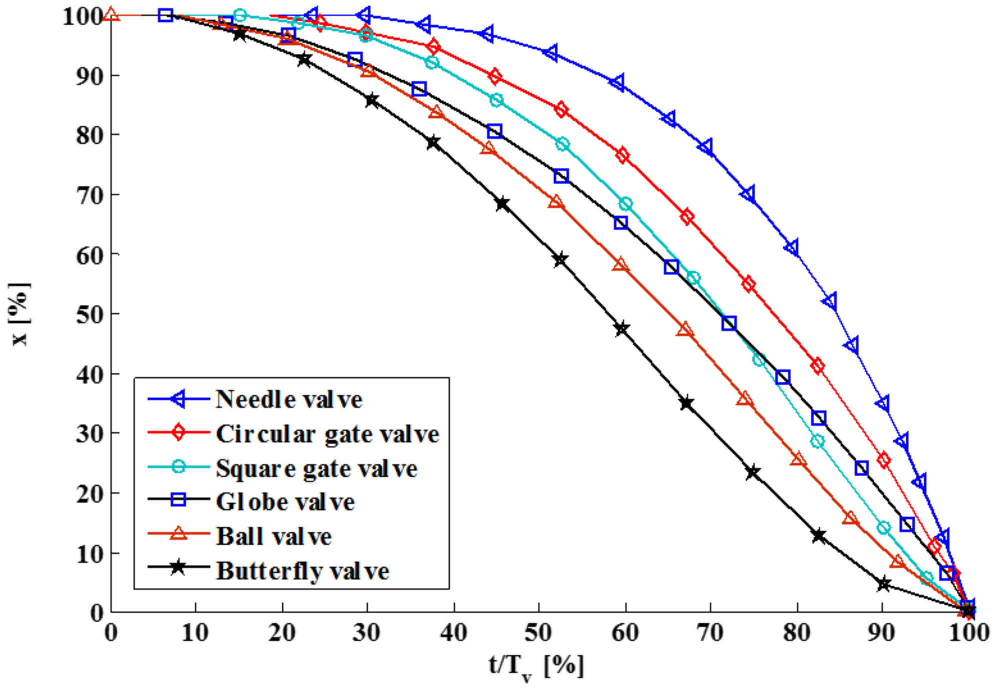

Figure 12: Valve Position During Accelerated Closure

5- Conclusion

In this paper, discusses The effect of opening and closing the valve on the water hammer through the laws of closure, how to open and close the valve, and between that through the previous diagrams. Also, through this paper, the valve types and the way each valve works with the operating function of the valves were known, and through the results it becomes clear the valve uniform and accelerated closures in figure (9) and (10) respectively so the circular gate valve flow area gradient evolves slowly during the first 50 % of closure before increasing, whereas the flow area gradient for a ball valve is important during the first 50 % of closure before decreasing. Uniform closure of a globe valve is characterized by a constant gradient. And Fluid velocity reductions for uniform closure of the six valves considered are shown in figure (11). The fluid velocity reduces slowly until 80 % of the fluid initial velocity, the fluid velocity then decreases rapidly until full closure. The fluid velocity reaches 80 % of the initial velocity at 87 %, 81 %, 76 %, 71 %, 65 % and 55 % of the actuation time for needle, circular gate, globe, square gate, ball and butterfly valves, respectively. Fluid velocity reductions for accelerated closure of the six valves considered are shown in fig (12). The fluid velocity reduces slowly until 80 % of the fluid initial velocity, the fluid velocity then decreases rapidly until full closure. The fluid velocity reaches 80 % of the initial velocity at 93 %, 90 %, 87 %, 81 %, 80 % and 74 % of the actuation time for needle, circular gate, globe, square gate, ball and butterfly valves, respectively. Practically, pressure waves originating from sudden valve actuations are generated mainly during the last 20 % of valve uniform actuation, or the last 10 % of valve accelerated actuation, as observed from figure (11) and figure (12). Fluid velocity gradients determine also pressure waveforms. Needle valves generate sharper waveforms than circular gate, globe, square gate, ball and butterfly valves.

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Article submitted 11 February 2023. Published as resubmitted by the authors 3 March 2023.