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IMPROVED EQUATIONS TO CALCULATE THE MINIMUM STEM TRAVEL IN GAS LIFT VALVES

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ABSTRACT

The minimum stem travel required to fully open an unbalanced, single-element Gas Lift Valve (GLV) is an important parameter in GLV performance calculations. The value of this parameter dictates whether the valve is fully or partially opened, thus determining the amount of gas passage through the GLV. The geometries of the ball and the seat are the main factors affecting this parameter.

There exists only one equation in literature to readily calculate this minimum stem travel required for a fully open GLV. However, the derivation of this equation is based on only one position of the ball which might not be the case for different ball and seat geometries. Also, this equation allows to calculate the minimum stem travel for sharp-edge seats only. Recently, detailed theoretical calculations were made and experiments were run based on modified seat designs (beveled seats) (Elldakli, Soliman, Shahri, Winkler, & Gamadi, 2014) which showed a significant performance improvement compared to sharp-edge seats. As minimum stem travel depends on seat geometries, the existing equation cannot be applied for the beveled seats.

In this paper, a set of new equations have been presented to calculate minimum stem travel for fully open GLV for any ball positions, and ball and seat geometry. In addition to the equation for sharp-edge seats, another equation has been derived for beveled seat based on average port area. This set of new equations is expected to make the relevant calculations more precise and correct.

KEYWORDS: Stem Travel, Single-Element Gas Lift Valve (GLV), GLV Performance

INTRODUCTION

Current GLVs are all based on King's design (King, 1940) and consist of a dome section, which is charged with gas (usually nitrogen) at a certain pressure. Another type of GLV is the benchmark GLV which does not have the nitrogen-charged dome and bellows assembly, and the stem position in relation to the valve seat is manually adjustable by the user. The information from benchmark valve could be applied to predict the stem travel for actual GLVs when the volumetric gas rate and upstream and downstream pressures are known this type of GLV is mainly used in laboratories for testing purposes. However, (Camp & Winkler, 1987) successfully used benchmark valve in field application. The basic components of both types of GLV are shown in Figure 1:

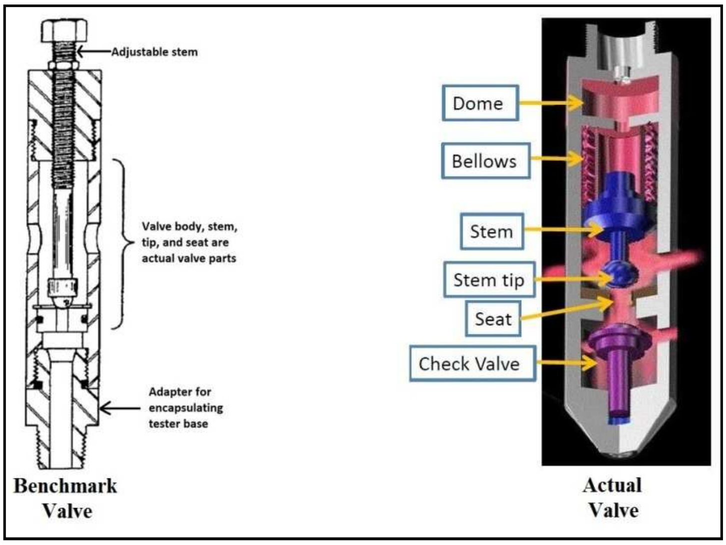

Figure 1: Basic Components of Benchmark and Actual GLV

On the top of an actual GLV, a dome seal is present for pressure charge and discharging purposes. The dome section is attached to a loading element. The loading element can be a nitrogen-charged bellows, a spring, or a combination of both. The bellows assembly is helical in shape and acts like a spring. The bellows are attached to the stem, which ends at the ball. These mentioned sections move as a single unit in each GLV. When the GLV is closed, the ball is seated onto a sized port area. A check valve on the downstream side of the port prevents the backflow from either the tubing or casing to interfere with one another.

As gas is injected the casing pressure rises, and applies on the bellows area. A fraction of the injection pressure acts on the ball pushing the stem down. This amount depends on the ball surface area. In static mode, the only pressure acting on the bellows is the dome-charged pressure, which is referred to as closing pressure. As the injection gas pressure increases, the force on the bellows increases, and when it exceeds the bellows set charge pressure, the GLV initially begins to open. The GL V opening mechanism is gradual. The stem travel in the actual GLV system is based on the difference between the opening and closing forces and the bellows-assembly load rate.

Flowing area is one of the most important parameters in each GLV. This area is generated by the stem movement away from the seat. The flow area for a partially open valve is defined by the lateral surface area of the frustum of a right circular cone. This frustum area is generated between the ball surface and the valve seat, and increases as the valve stem moves away from the seat. The major area of the frustum is the ball/seat contact area, which remains constant. The minor area, which is the top plane of the frustum, decreases with an increase in stem travel as the ball moves away from its seat. When the frustum area becomes equal to the port area, which is constant for a sharp-edge seat and variable for a beveled seat, the GLV fully opens and provides maximum gas throughput (Winkler & Blann, 2006). However, it is recommended to have a stem travel that allows at least 125% fully open GLV (Shahri, 2011)to eliminate the effect of the presence of the ball (Coanda effect).

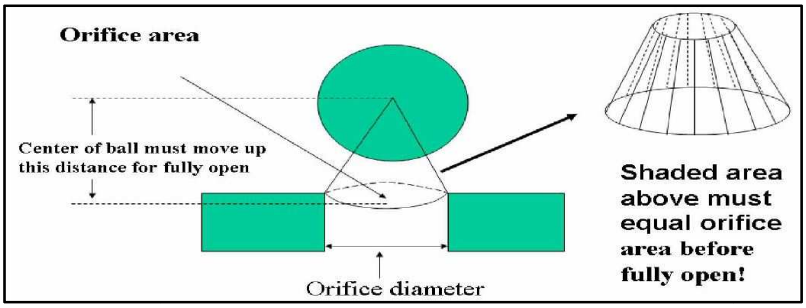

Figure 2: Change of Frustum Area as the Ball Moves Up

EQUATIONS TO CALCULATE MINIMUM STEM TRAVEL

Existing Equation

Equation **Error! Reference source not found.** was given by (Kulkarni, 2005) to calculate the minimum stem travel required for a fully open GLV based on sharp-edge seat geometry.

$$y = r_p \times \tan\left\{\cos^{-1}\left(\frac{-r_p^{\,2} + \sqrt{r_p^{\,4} + 4 \times r_b^{\,2} \times r_p^{\,2}}}{2 \times r_b^{\,2}}\right)\right\} - \sqrt{r_b^{\,2} - r_p^{\,2}} \tag{1}$$

Equation **Error! Reference source not found.** was modified by (Elldakli, Soliman, Shahri, Winkler, & Gamadi, 2014) to fit the beveled seat design.

$$y = r_{pt} \times \tan\left\{\cos^{-1}\left(\frac{-r_{pb}^{\,2} + \sqrt{r_{pb}^{\,4} + 4 \times r_b^{\,2} \times r_{pt}^{\,2}}}{2 \times r_b^{\,2}}\right)\right\} - \sqrt{r_b^{\,2} - r_{pt}^{\,2}} \tag{2}$$

The geometric figure used to derive the original equation is as follows.

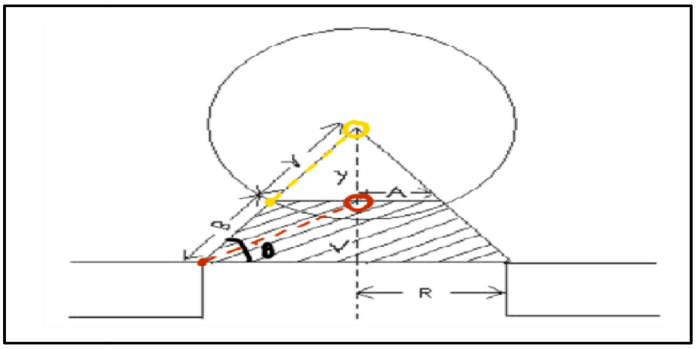

Figure 3: The Geometric Figure for the Original Derivation (Kulkarni, M.N., 2005)

However, the issue with Equation **Error! Reference source not found.** and Equation **Error! Reference source not found.** is these are based on only one position of the ball. This means that this particular figure might not be applicable for other combinations of position of the ball and/or geometry of the seat. This is illustrated in Figure 4.

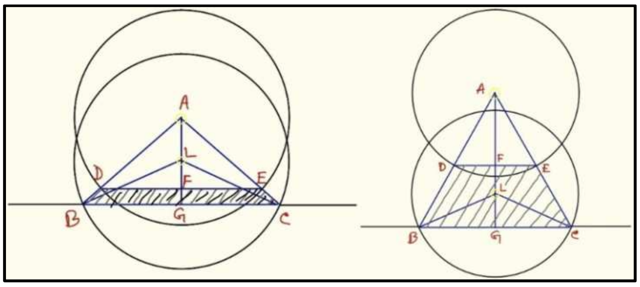

Figure 4: Geometric Figures Used for New Equations (Sharp-Edge Seats)

In Figure 4, two different positions of the ball are shown. The left one shows that the center of the ball's changed position is still under the area of the balls initial position. In the right one, the center of the ball's changed position is outside of the area of the ball's initial position. If Figure 3 is used to calculate stem travel, then according to Figure 4 which is drawn to scale, the stem travel would be calculated as AF whereas the actual stem travel is AL (change in the position of the ball's center, marked in yellow). So, for the first case, the calculated stem travel would be an overestimation and for the second case, an underestimation.

Also, Equation **Error! Reference source not found.** is only applicable for sharp-edge seat. Although Equation **Error! Reference source not found.** was modified to give Equation **Error! Reference source not found.** to fit the beveled seat geometry, the derivation was still based on the original geometric figure (Figure 3). As opposed to the sharp-edge seat design, the port area is not constant in beveled seat. So, in the development of the respective equation, the average port area should be considered rather than a constant port area.

Modified Equations

Considering on the limitations of the existing equations, a set of new equations have been derived. These equations are presented below.

Sharp-Edge Seat

$$x^2 - r_p x - r_b{}^2 = 0 \tag{3}$$

Where,

$$x = \sqrt{\left(y + \sqrt{r_b{}^2 - r_p{}^2}\right)^2 + r_p{}^2} \tag{4}$$

Beveled Seat

$$x^2 - bx - r_b{}^2 = 0 \tag{5}$$

Where,

$$x = \sqrt{\left(y + \sqrt{r_b{}^2 - r_{pt}{}^2}\right)^2 + r_{pt}{}^2} \tag{6}$$

And,

$$b = \frac{h}{3h_2 r_{pt}}\left[\left(\frac{3h_2 - 2h}{h}\right) r_{pb}{}^2 + r_{pt}{}^2 + r_{pb} r_{pt}\right] \tag{7}$$

In these non-linear equations, x is just a simplifying parameter and parameter b dependents on the geometries of the beveled seat.

RESULTS COMPARISON

Table 1: Minimum Stem Travel Comparison between the Previous Equation and the New Equation

GLV Size (in)	Seat Type	PBD* (in)	PTD* (in)	BPH* (in)	Seat Height (in)	Ball Diameter^ (in)	y_{old}^* (in)	y_{new}^* (in)	Difference (%)
1	Sharp-edge	1/8	1/8	-	0.39	3/16	0.0442	0.04593	3.93589
		5/32	5/32			7/32	0.0576	0.06031	4.77656
		3/16	3/16			1/4	0.0714	0.07186	0.61569
		1/4	1/4			5/16	0.1003	0.10014	0.11466
		5/16	5/16			3/8	0.1302	0.12966	0.41928
	Beveled (Modified)	1/8	5/32	0.117		7/32	0.0362	0.08934	146.57644
			3/16			1/4	0.0313	0.08977	187.09781
			1/4			5/16	0.0253	0.09666	281.32108
			5/16			3/8	0.0219	0.11000	403.09154
	Beveled (Optimized)	1/8	5/32	0		7/32	0.0362	0.09635	165.91026
			3/16			1/4	0.0313	0.09858	215.26256
			1/4			5/16	0.0253	0.11728	362.66630
			5/16			3/8	0.0219	0.13451	515.19080
1.5	Sharp-edge	3/16	3/16	-		1/4	0.0714	0.07024	1.65040
		1/4	1/4			5/16	0.1003	0.10014	0.11466
		5/16	5/16			3/8	0.1302	0.12966	0.41928
		3/8	3/8			7/16	0.1610	0.16076	0.14707
		7/16	7/16			1/2	0.1924	0.19144	0.52126
		1/2	1/2			9/16	0.2244	0.22450	0.03854
	Beveled (Modified)	1/8	3/16	0.125		1/4	0.0313	0.08893	184.39356
			1/4			5/16	0.0253	0.09523	275.68188
			5/16			3/8	0.0219	0.10395	375.39982
			3/8			7/16	0.0195	0.11773	503.16822
			7/16			1/2	0.0178	0.13100	635.79065
			1/2			9/16	0.0165	0.14485	778.93975
	Beveled (Optimized)	1/4	1/2	0		9/16	0.0615	0.25925	321.37683
			9/16			5/8	0.0575	0.27950	386.05563
		5/16	1/2			9/16	0.0931	0.29895	221.21606
			9/16			5/8	0.0867	0.31630	264.65277
		3/8	1/2			9/16	0.1305	0.34171	161.86259
			9/16			5/8	0.1211	0.35699	194.82974

*PBD = Port bottom diameter, PTD = Port top diameter, BPH = Bottom port height, y_{old} = Minimum stem travel based on the previous equation, y_{new} = Minimum stem travel based on the new equation

^ Ball diameter = PTD + 1/16" (Gas-lift Valve Performance Testing, 2001)

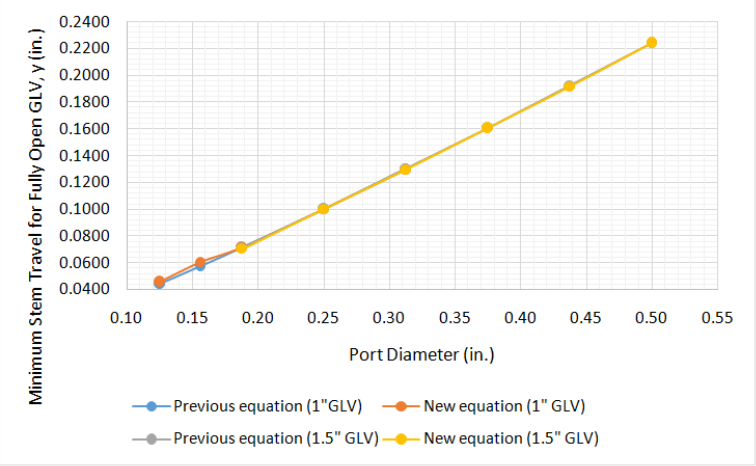

Chart 1: Comparison between the Two Equations for Sharp-Edge Seat

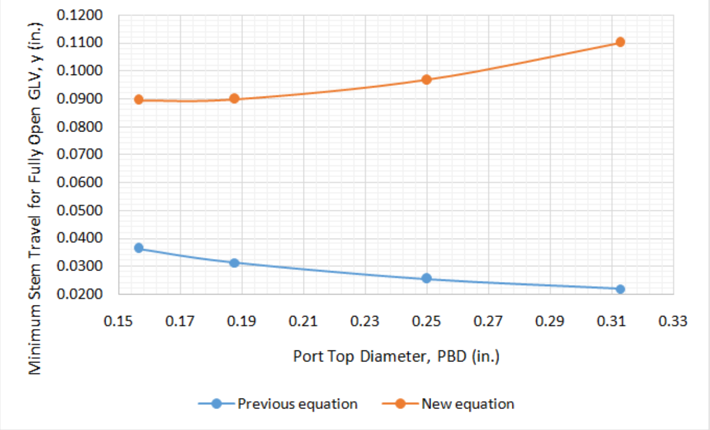

Chart 2: Comparison between the Two Equations for Modified Beveled Seat with 1/8-in. PBD (1" GLV)

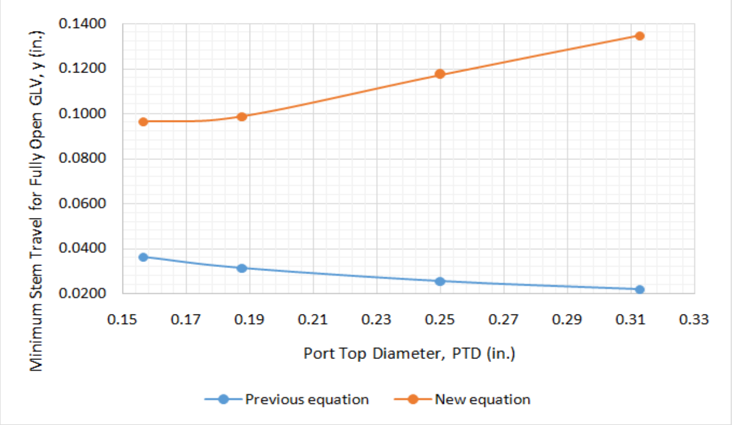

Chart 3: Comparison between the Two Equations for Optimized Beveled Seat with 1/8-in. PBD (1" GLV)

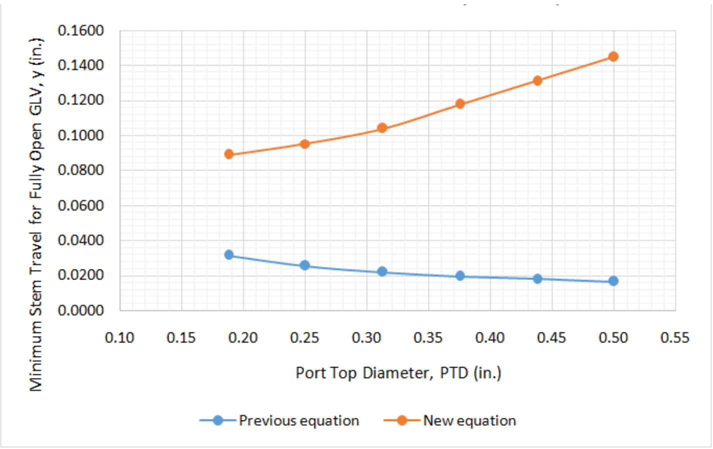

Chart 4: Comparison between the Two Equations for Modified Beveled Seat with 1/8-in. PBD (1.5" GLV)

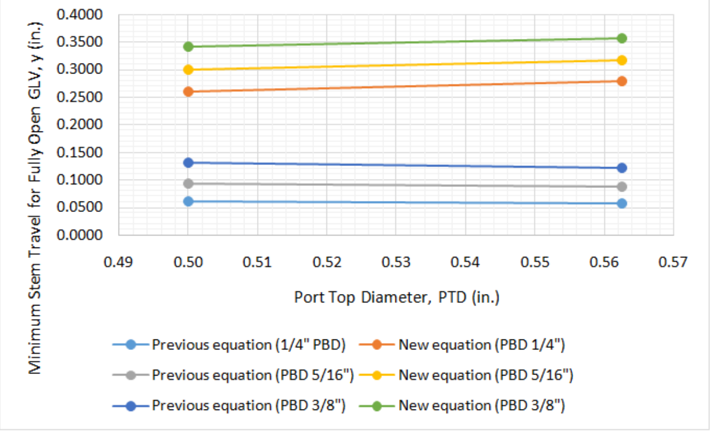

Chart 5: Comparison between the Two Equations for Optimized Beveled Seat (1.5" GLV)

CONCLUSIONS

The following conclusions can be drawn from the results of this work:

- A new set of equations has been derived based on more accurate geometries to calculate the minimum stem travel for fully open GLV for both sharp-edge and beveled seat designs.
- The difference in minimum stem travel required for fully open GLV for sharp-edge seat design with the exiting equation and the new equation is comparatively small (maximum 5%).
- The difference in minimum stem travel required for fully open GLV for beveled seat design with the exiting equation and the new equation is significantly large (as high as 750%).
- With increasing port diameter (sharp-edge seats) (Winkler & Blann, 2006) or port top diameter (beveled seats), the required stem travel to fully open the GLV increases. The new equation conforms to this trend. However, the existing equation shows a decrease in stem travel with increasing port top diameter.

LIST OF VARIABLES

r_p = Port radius (sharp-edge seat)

r_b = Ball radius

r_{pt} = Port top radius (beveled seat)

r_{pb} = Port bottom radius (beveled seat)

h_2 = Seat height

h = Height of the beveled segment (beveled seat)

y = Minimum stem travel required for fully open GLV

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