ZERO RESTRICTION STANDING AND TRAVELING VALVES IN A ROD PUMP

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ABSTRACT

Standing and Traveling valves can be considered as the heart of a rod pump. An unrestricted fluid flow through the standing and traveling valves improve the pump efficiency and pump life. An unrestrained fluid flow through the traveling valve helps the sucker rod string to fall freely, which reduces rod buckling and eliminates unnecessary load on the surface unit. And in the case of the standing valve, it reduces the velocity and pressure drop across the cage, which lessens the gas lock in a pump. Standing valves with the least unused volume provide the highest compression ratio, which is helpful in a gassy environment. Zero restriction flow through the cages provides a free flow for the wellbore fluids with solid particles and keeps the cages from blockage.

The important factors that need to be considered while selecting standing and traveling valves are: 1) Compression ratio, 2) Zero restriction flow, 3) Pressure drop and 4) Ball rattle, which will be discussed in this paper.

The research team at Ellis Manufacturing has studied these factors along with different patterns of flow and engineered the patented Ellis JMAX 1-Piece Insert Cages. This paper discusses how the carefully engineered JMAX cages address all four important factors to provide improved pump efficiency for pumping in both conventional and horizontal wellbores.

ROLE OF STANDING AND TRAVELING VALVES IN A ROD PUMP

Sucker rod pumps are a type of artificial lift system that use a reciprocating motion to lift fluids from oil wells. They are widely used in the oil and gas industry because of their low cost, high efficiency, and adaptability to various well conditions.

A sucker rod pump system consists of four main components: a prime mover, a surface pump unit, a sucker rod string, and a downhole pump. The prime mover is an engine or a motor that provides power to the surface pump jack. The surface unit or the pump jack is a beam pump that converts the rotational motion of the prime mover into a vertical reciprocating motion that lifts and lowers the rod string. The rod string is a series of steel or fiberglass rods that connect the surface unit to the downhole pump. The downhole pump (Figure 1) is a positive-displacement pump that captures and lifts the formation fluids up the production tubing.

The working principle of a sucker rod pump is based on the pressure difference between the inside and the outside of the downhole pump. When the rod string moves upwards, the plunger of the downhole pump moves upwards along with it, the traveling valve connected to the plunger closes and moves upwards along with the plunger creating a low pressure chamber inside the pump barrel. This causes the fluid from the reservoir to enter the pump through the standing valve at the bottom of the pump. This low pressure chamber between the traveling and standing valve is compressed and expanded throughout the cyclic pumping action. When the rod string moves downwards, the plunger along with the traveling valve moves downwards. During the downward travel, the standing valve closes, and the fluid trapped between the traveling and standing valves get compressed creating a high pressure inside the chamber. This causes the traveling valve to open and the fluid inside the pump exits at the top of the pump and flows up the tubing to the surface. These valves are simple check valves and operate on the ball-and-seat principle (Figure 2). The ball and seat form a reliable seal to handle a very high differential pressure across the valve during pumping.

The performance and the runtime of the pump is greatly dependent on the design nuances of the standing and traveling valves. Both standing and traveling valves are required to operate in challenging well bore conditions such as deviated well bores, high gassy and corrosive environments, presence of sand, solids, and paraffin in the well bore fluids. The comprehensive design of standing and traveling valves involves careful consideration of the factors that influence the performance of the sucker rod pumps. These important factors 1) Compression ratio, 2) Zero restriction flow, 3) Pressure drop and 4) Ball rattle will be discussed here in detail based on comparative study and lab testing. The design cues obtained by this careful study of these factors were applied to design the JMAX cage.

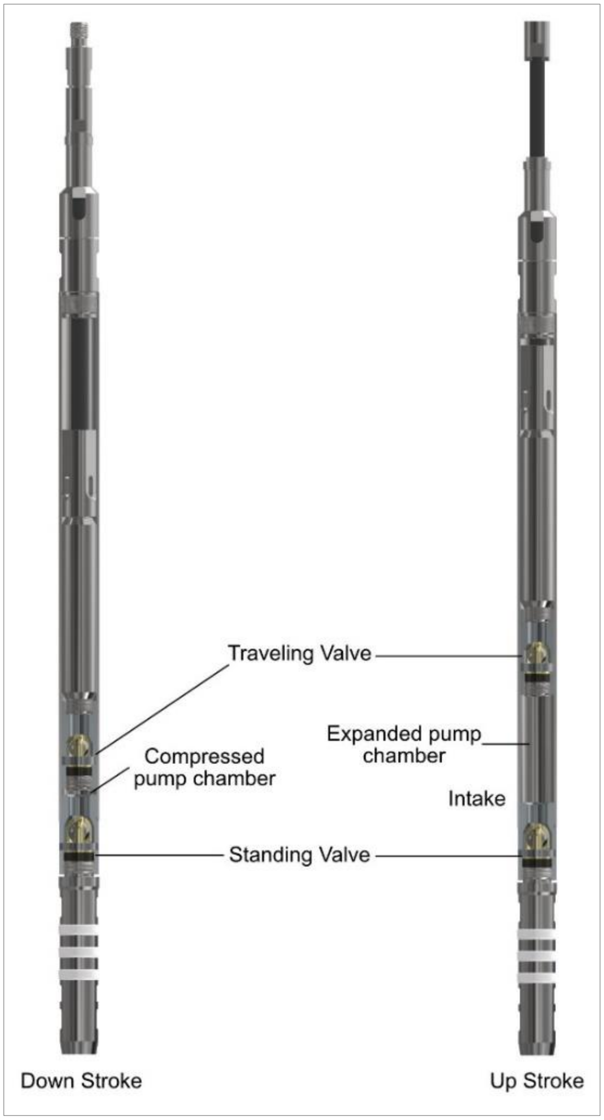

Figure 1

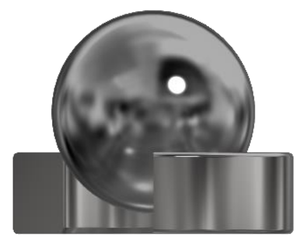

Figure 2

FLOW LOOP TO TEST CAGE PERFORMANCE

The flow loop was designed and developed with appropriate instrumentation to test the ball rattle, pressure drop and flow rate across a given cage valve. The flow loop as shown in Figure 3, is equipped with a pump (P) that can pump water at the rate of 0-25 GPM from a reservoir (T). Water is pumped through the manually controlled directional check valve (MV) in series through a digital flow rate measuring device (FRM). This flow rate measuring device records the flow rate of the fluid as it passes through the cage. A pressure gauge (PG) is connected in line to record the pressure before the fluid enters the cage. A capsuhelic differential pressure gauge (DG) is used to record the pressure as the fluid enters and exits the cage at (L) and (H) respectively and measure the pressure difference in inches of water column. The flow loop is equipped with a decibel meter (DM) to measure the ball noise in decibels as the fluid flows through the cage. The decibel meter is maintained at a constant distance of 3/8" from the cage to measure ball rattle for different cage configurations at different flow rates. The test was conducted with standard API and alternate API ball configurations at a flow rate of 2 GPM (68.6 BPD) to the maximum cage flow rate capacity in increments of 2 GPM. The test was repeated multiple times for each cage configuration to record average maximum flow through cage (gpm), ball rattle (db.) and pressure drop (wc) at different flow rates. The results obtained from the flow loop were used in conjunction with the appropriate calculations to decipher the nuances of the valve design. This led to the design of JMAX valve cages that can operate with lowest pressure drop, with no ball rattle and without restriction in the flow area at different flow rates.

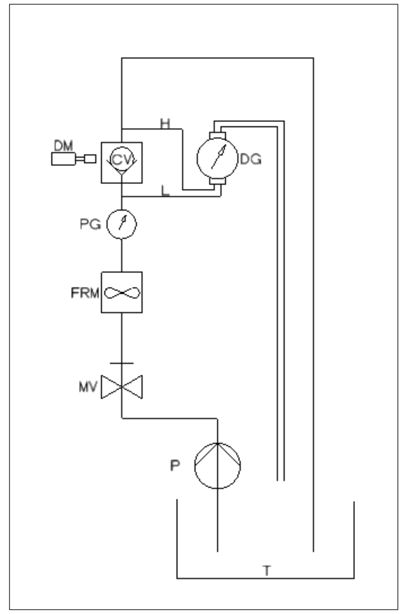

Figure 3

COMPRESSION RATIO:

The compression ratio is the ratio of the absolute stage discharge pressure, i.e. the pressure at the end of the pump stroke to the absolute stage suction pressure, i.e. the pressure at the start of the downstroke. It represents how much the pump chamber compresses the fluid during its operation. Pump designers and operators consider the compression ratio when selecting and sizing sucker rod pumps. Properly mating the pump's compression ratio to the production requirements is crucial for efficient and reliable operation.

Compression ratio plays a crucial role in determining the efficiency of a sucker rod pump. The following is how the compression ratio impacts the pump performance:

Efficiency and compression ratio:

- The compression ratio directly affects the pump's ability to handle gas-liquid ratio efficiently.
- When the compression ratio is too low, the pump may struggle with gas locking, leading to reduced efficiency.
- Conversely, if the compression ratio is too high, it can cause excessive wear and energy losses.

Effects on Pump Efficiency:

- Optimal Compression Ratio: Achieving the right balance is essential. An ideal compression ratio ensures:
  - Effective fluid lifting without excessive gas interference.
  - Minimal energy wastage during compression and expansion.

Undercompression (Low Ratio): This can happen when there is excessive dead space or unwept volume. Some of the effects of low compression ratio are:

- Inadequate compression leads to incomplete fluid displacement.
- Gas pockets may accumulate, hindering pump performance.
- Efficiency drops due to wasted energy.

Overcompression (High Ratio): This is a result of improper selection of the length of the pump. Some of the effects of excessive compression are:

- Excessive compression can damage pump components.
- Increased friction and energy losses occur.
- Efficiency decreases due to unnecessary work.

Calculating the compression ratio in a sucker rod pump involves understanding the volume changes within the pump chamber during its operation as shown in Figure 4. Compression ratio (CR) is represented by Swept volume + Unswept volume divided by the Unswept volume.

Compression ratio (CR) = (Swept Volume + Unswept) / Unswept Volume

Varying the sucker-rod pump components and close spacing will alter the compression ratio; however, some of these components like Standing Valve are not carefully designed to increase compression ratio. This can increase waste space in the pump, resulting in a decreased compression ratio. It is important that the standing valve is designed with the least unswept volume to get maximum compression ratio in any given pump as shown in Figure 5 and Table 1.

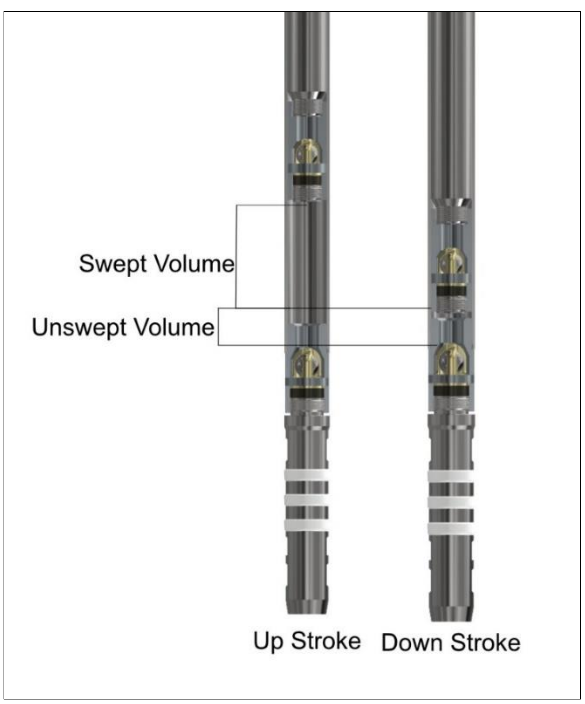

Figure 4

Figure 5

TABLE 1: UNUSED VOLUME COMPARISION			
STAINDING VALVE	JMAX CAGE UNUSED VOLUME [in^3]	STANDARD CAGE UNUSED VOLUME [in^3]	JMAX COMPRESSION RATIO IMPROVEMENT [%]
1-3/4	1.14	2.33	51.1
1-3/4 XTREME	0.1	NA	95.6
2-1/4	1.54	3.18	51.6
2-1/4 XTREME	0.17	NA	94.6
2-1/4 COMP	0.14	2.1	93.3

ZERO RESTRICTION FLUID FLOW

Both standing and traveling valves have long been plagued with either restricted fluid flow area or thinner wall thickness. Flow through the seat ID is the maximum flow area on any given cage. The flow area around the ball in the current designs of standing and traveling valves are restricted to prevent premature bursting of the valves when they are subjected to sudden high pressure situations like fluid pounding. The restriction in the flow area is more when a full size API ball is used compared to Alternate pattern API ball (Figure 6). As the fluid flows through a restricted standing valve the velocity of the flow increases. This can be understood with Bernoulli's principle (Figure 7).

*A1 * V1 = A2 * V2*

*V2 = (A1 * V1) / A2*

A1, V1 are the flow area and velocity as the fluid enters through the seat ID or the intake conditions. A2, V2 are the flow area and velocity as the fluid exits the maximum diameter of the ball in the cage or the discharge conditions. In general, the flow area around the ball in a cage is the most restricted flow area. With the reduction of flow area, the velocity increases. Table 2 shows the flow area though the seat ID and around the ball in cages.

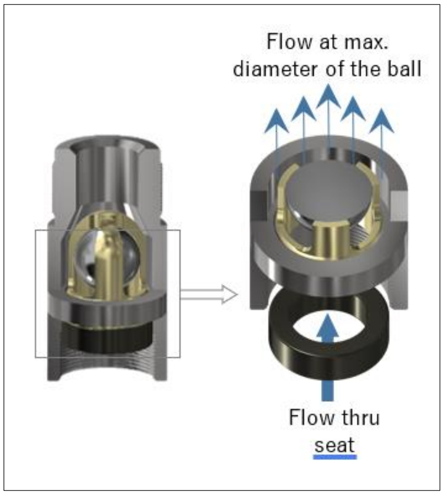

Figure 6

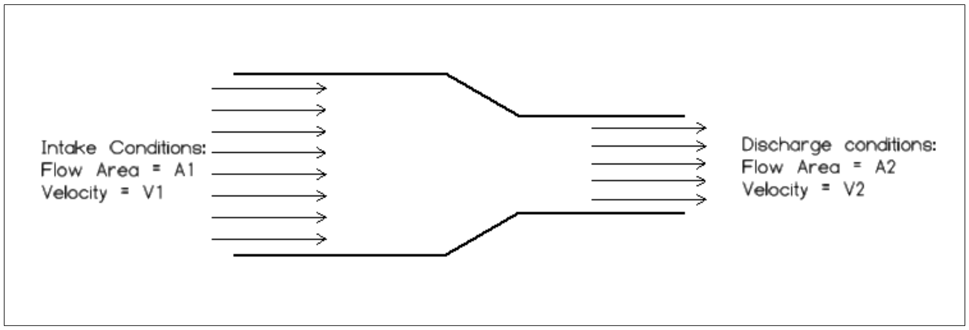

Figure 7

TABLE 2: FLOW AREA COMPARISON					
SEAT SIZE	SEAT ID AVG (in)	SEAT FLOW AREA (in^2)	JMAX FLOW AREA WITH ALT BALL (in^2)	STANDARD CAGE FLOW WITH ALT BALL (in^2)	STANDARD CAGE FLOW AREA WITH STD BALL (in^2)
1.25	0.55	0.238	0.253	0.179	0.108
1.5	0.67	0.353	0.364	0.261	0.171
1.75	0.825	0.535	0.547	0.433	0.224
2	0.96	0.724	0.747	0.493	0.26
2.25	1.06	0.882	1.018	0.551	0.293

When dealing with restricted flow areas in the valves of sucker rod pump, several problems can arise such as:

Flow restriction at Standing Valve:

The standing valve is responsible for allowing fluid to enter the pump barrel during the upstroke, when it is restricted, it can lead to:

- Reduced production efficiency: less fluid enters the pump, affecting overall pump performance.
- Increased pressure drops: The pressure from the well's intake to inside the pump barrel may drop significantly.
- Gas breakout: The pressure drop can cause gas to separate from the fluid, leading to gas interference and reduced pump efficiency.
- Increased fluid velocity: The velocity of the fluid increases around the ball and causes the ball to rattle leading the cage and ball to fail.

Flow restriction at Traveling Valve:

The traveling valve is responsible for discharging the fluid inside the pump at the top of the pump that flows up the tubing to the surface, when it is restricted, it can lead to:

- Restriction in the flow through the traveling valve will put the sucker rod string in compressive stress causing the sucker rods and valve rod to buckle (Figure 8).
- Rod buckling may lead to excessive wear and tear on the tubing and rod string (Figure 9).
- Fluid in the pump chamber gets compressed excessively to the extent it can damage the pump components like split cages, split barrel, breaking valve rod at the last thread (Figure 10).
- It will lead to increased friction and energy losses on the surface unit leading to an overall decrease in efficiency.
- Discharge velocity increases significantly leading to excessive ball rattles inside the cage (Figure 11). It may cause the cage to fail prematurely.

Figure 8

Figure 9

Figure 10

Figure 11

No restriction flow through the standing valve and traveling is important because of the effect it has on the pump fillage, gas breakout and compressive loads on the valve rod and rod string. The test results showed that insert cages with alternate pattern ball have a better flow area and flow rate compared to machined cages. It is also found that most of the insert cages are still restrictive on the fluid flow area compared to the flow through the seat ID. It was found that out of 8 different manufacturer's standing valves tested on the flow loop, JMAX cage was able to pump at maximum flow rate compared to any other cage. This is due to no restriction flow through the cage around the maximum diameter of the ball as shown in Table 3.

TABLE 3: MAXIMUM FLOW THROUGH A 2.25 STANDING VALVE CAGE

	Machined 2.25 cage with 1-3/8 ball	Machined 2.25 cage with 1-3/8 ball	4 piece Insert guided 2.25 cage	No restriction JMAX 2.25 cage
Max free* flow (gpm)	13.73	13.49	14.51	14.92
Max free* flow (bpd)	470.74	462.51	497.49	511.54

*Max free flow rate indicates the flow through the cage is not forced. Higher flow rates can be achieved with a pressurized flow.

PRESSURE DROP ACROSS THE STANDING VALVE

The primary function of the standing valve is to allow fluid to enter the pump during the upstroke of the pump cycle. As the fluid flows through the standing valve, there is resistance due to various factors like the geometry and design of the standing valve that creates the flow resistance, restricted flow area and surface roughness of the valve cage. Excessive ball rattle inside the ball chamber can also cause the gas to breakout. The pressure drop across the standing valve may let the dissolved gas in the fluid break out of the solution and form bubbles. These gas bubbles can accumulate inside the pump, leading to issues like gas lock and reduced pump efficiency. Gas breakout can be detrimental, causing erratic pump behavior and reduced production.

Lab tests have shown that with an increase in flow rate, pressure drop increases dramatically when the flow area around the ball is less than the flow area through the seat. Most valve cages that were tested have a restricted flow area and have exhibited higher pressure drop with increased flow rates. JMAX cage exhibited a consistent performance across different flow rates due to no restriction flow around the ball (Table 4).

TABLE 4: PRESSURE DROP ACROSS CAGE		
FLOW RATE US gpm (bpd)	JMAX CAGE WITH NO FLOW RESTRICTION 2-1/2 SV (wc)	STANDARD API 2.25 SV (wc)
2 (68.6)	6	14
3 (102.9)	6	13
4 (137.1)	7	11
6 (205.7)	7	8
8 (274.3)	8	14
10 (342.9)	8	21
12 (411.4)	9	29
14.92 (511.5)	12	39

BALL RATTLE AND BALL CLEARANCE:

Excessive ball rattle in sucker rod pump cages can lead to several issues that impact pump efficiency and reliability. Ball rattle causes ball wear and cage failure due to continuous pounding of the ball against the insert or the ball guides of the cage and may damage both the ball and the cage prematurely. The vibrations (chatter) induced inside the ball chamber exacerbate this wear. When the ball wears out or the cage fails the pump can no longer create a proper seal, affecting overall performance. Excessive ball rattle can cause gas breakout due to increased pressure drop, this free gas fills up the pump chamber and causes gas lock affecting the overall performance of the pump with reduced production flow and increased operational costs. Efforts to minimize the ball rattle and improve sucker rod pump performance are crucial for maintaining reliable pump performance. The geometry and the ball clearance of the ball chamber plays a crucial role in minimizing the ball rattle. Lab tests have shown that with ball rattle is higher with alternate pattern ball compared to standard ball irrespective of machined cage or insert cage.

Clearance between the ball and the ball guides inside the cage is a very important factor to be considered to reduce the ball chatter. Usually, cages are designed with a diametric clearance of 0.025”-0.035”. From the lab tests it is found that the more clearance the more ball rattles creating more vibrations leading to premature failure. Lab tests showed that the tighter the clearance lowers the ball chatter with improved cage life. It is also found that the ball rattle is higher with alternate pattern ball compared to standard ball irrespective of machine cage or insert cage when the diametrical ball clearance is 0.025”-0.035”.

Ball chamber geometry:

Ball chamber geometry is another important factor to reduce the ball chatter. It is observed that the ball chamber with a flat ball stop (Figure 13) or ball chamber machined with 3 holes (Figure 14) has a higher ball rattle compared to a dome shaped ball stop (Figure 12). It is found that that domed shaped ball chamber has eliminated the ball rattle all together.

Figure 12

Figure 13

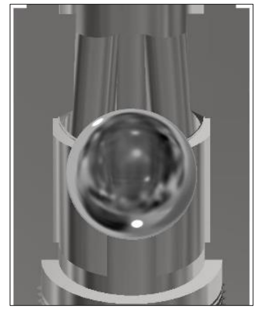

Figure 14

Tighter ball clearance vs vortex fluid path:

A detailed study has been conducted to find out the best possible way to reduce ball chatter. It is found that vortex fluid path with 0.025” – 0.035” diametrical clearance reduces the ball chatter up to 43% compared to a regular a straight fluid path with same amount of clearance. But the less chatter behavior is inconsistent at different flow rates. Whereas a cage with tighter diametrical clearance eliminates the ball chatter altogether. It is also found that vortex fluid path is not continuous during the pumping cycle, and it gets disrupted on every downstroke. Because of the vortex disruption in the downstroke, not enough velocity is generated to reduce the pressure drop or to eliminate ball chatter all together. Other than spinning the fluid around the ball no significant improvement has been observed in the ball rattle or pressure drop by a vortex pattern geometry. The test date is given in Table 3 and Table 5.

TABE 5: BALL RATTLE COMPARISON

	Flow Rate (gpm)	JMAX Cage 2.25 SV	4 Piece Insert Cage with Alt Ball 2.25 SV	4 Piece Insert Cage with Reg. Ball 2.25 SV	Machined Cage with ALT Ball 2.25 SV	Machined Cage with Reg. Ball 2.25 SV
Ball Rattle (db)	2	46.3	61.3	62.4	71.2	74.3
	3	45.8	69.1	64.4	75.5	76
	4	45.8	75.9	64.7	77.1	76.1
	6	46.1	73.8	66.7	79.6	72.8
	8	46.1	75.3	68.2	80.9	76.5
	10	46.2	70.3	68.2	83.7	80.3
	12	48.3	71.3	69.4	84.5	82.9
	at Max. flow	49.2	71.5	70.4	86.3	85.1

JMAX CAGE DESIGN AND PERFORMANCE:

JMAX cage was designed from ground up to get uncompromised performance in all four aspects that were discussed. The cage is engineered to reduce the ball rattle and provide zero-restriction flow without reducing the wall thickness. It is also carefully designed to have a high compression ratio and perform at low pressure drop at all different flow rates. To get the zero restriction flow without reducing the wall thickness it is found that the fluid should flow in a specialized path instead of flowing through the insert as shown in Figure 15 and 16.

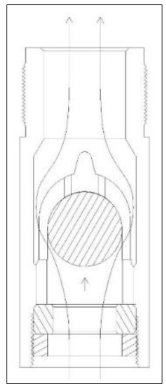

Figure 15

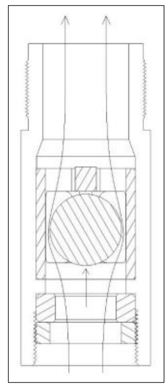

Figure 16

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