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Research Article

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Study of the Function, Design, Operational Life and Simulation of an Over-Center Valve in Hydraulic Systems

Ameer Tuama Abd Ulhussein
Ministry of Higher Education, Iraq

Abstract: Hydraulic systems have long played a central role in executing heavy industrial operations, such as lifting loads or driving equipment like excavators and trucks. One of the most common challenges facing these systems is maintaining load stability during sudden dynamic shifts, such as a change in the center of gravity when lifting a load with cranes or traversing uneven terrain. These situations impose abnormal loads on the hydraulic system, which can damage components, reduce equipment lifespan, or endanger the operator. In response to these challenges, the over-center valve design emerged as a key solution. This paper discusses the function, design evolution, operational lifespan, and simulation analysis of over-center valves in hydraulic circuits. It compares standard, part-balanced, and fully balanced valve types, clarifying how each responds to back pressure and pilot control under different operating conditions. The study emphasizes the importance of proper material selection, seal quality, and routine maintenance in extending the life of the valve. Using FluidSIM software, a simulation was performed to demonstrate the valve's role in absorbing dynamic load variations and maintaining controlled motion during load reversal. The results highlight the valve's effectiveness in stabilizing system behavior during transient phases. The study concludes that over-center valves are essential components for ensuring system safety and performance, especially in closed-center and heavy-load applications. Their ability to manage sudden changes in load direction while protecting the hydraulic circuit makes them indispensable in modern hydraulic system design.

Keywords: Over-center valves; hydraulic system; FluidSIM; excavators; hydraulic control systems.

INTRODUCTION

Hydraulic systems have always been tasked with carrying out heavy industrial work, whether lifting heavy loads or moving heavy equipment such as excavators and trucks. One of the most common problems facing these systems is the stability of loads during sudden shifts and changes, such as a sudden change in the center of gravity when lifting a certain load in the case of cranes, or facing a slope in the road after traveling for a period of time on a flat road or uphill, which adds the weight of the excavator or truck to the load that must be overcome by the hydraulic system, which is considered an abnormal load with disastrous consequences for both the hydraulic elements used and the mechanism and even the life of the operator. Here, the design and use of over-center valves was a radical solution to overcome these sudden dynamic changes. (Processes, 2023)

Especially in hydraulic and pneumatic applications, over-center valves are essential parts of fluid control systems. These valves control a system's fluid flow's pressure, force, and direction. They are essential in many industries, including manufacturing and construction, due to their capacity to control precise movements and endure high pressure. But like any mechanical part, their lifespan is influenced by a number of variables, including design, operating environment, and maintenance procedures. (Liu, J. *et al*., 2024)

The operational life of over-center valves is a frequently disregarded yet essential element in ensuring the dependability and security of fluid control systems. By understanding the causes of valve wear, recognizing the warning signs of failure, and implementing best practices for maintenance, engineers and operators can significantly extend the lifespan of these components. This article will look at these elements in detail in order to optimize the working life of over-center valves. (Taheri, A. *et al*., 2023)

Definition and Function

An over-center valve is a type of load-holding and motion-control valve designed specifically to prevent uncontrollable movement in hydraulic systems, particularly in the presence of overrunning (negative) loads. These valves get their name from their capacity to control loads that are over-center with respect to the actuator or that pass by. (Solorio, J. A. *et al*., 2022)

Therefore, the Primary Functions for over-center valves are defined as follows:

- When the directional control valve is in neutral, load holding locks the hydraulic fluid in the actuator.
- **Controlled Movement:** Prevents load acceleration during lowering operations.
- **Cavitation Prevention:** Stops vacuum formation in the cylinder during sudden load shifts Back. (Kikuwe, R. *et al*., 2021)

***Corresponding Author:** Ameer Tuama Abd Ulhussein

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- **Pressure Maintenance**: Ensures smooth operation by maintaining minimum back pressure.

The over-center valves also have a role in Managing Overrunning Loads:

- **In mobile equipment** (like boom lifts): Prevents sudden boom drops if hydraulic lines fail.
- **In cranes:** Controls load lowering speed regardless of weight variations.
- **During downhill operations**: Prevents equipment from running away due to gravity.
- **In winch systems:** Maintains controlled cable tension during load lowering.

From the above, Over-center Valves are best for:
• Dynamic load applications with frequent movement. (Jaiswal, S. *et al*., 2024)
• Mobile equipment with boom or crane functions
• Applications where loads can shift direction (overrunning to resistive).
• Equipment that requires precise motion control during deceleration.
• Systems where safety during load lowering is critical.

Types of Over-Center Valves
Over-center valves come in various designs, each suited to different applications:

- Manual Over-Center Valves: Controlled by hand-operated levers or handles, these valves are typically used in low-volume, non-automated systems. (Processes, 2023)
- Electric Over-Center Valves: These valves are controlled by electric actuators and are used in systems requiring automated or remote operation.
- Hydraulic Over-Center Valves: These valves are controlled by hydraulic actuators and are common in large-scale industrial and construction applications. (Processes, 2023)

General Description of Over-Center Valve
In addition to opening the valve at a low level, the pressure PL will ensure that the valve closes in the event that the PL pressure drops as a result of the load exceeding its capacity. The image below provides a schematic description of the over-center valve's physical implementation, which is the subject of this paper. (Processes, 2023)

Figure 1 illustrates how the return pressure PR opposes the pressure from the upstream controlled load PL, which acts on the relatively large control area Ac on the control piston. Although the control piston and flow control spool are not connected, they can be considered one unit when the pressure PL exceeds the pressure PR. In contrast to the return pressure PR, the pressure downstream the motor Po acts directly on the flow control spool. (Kosova, F., & Unver, H. O. 2023)

A relatively narrow damping restrictor dampens the control piston. Without the assistance of the control piston's damping restrictor, the flow control valve can function as a quick pressure relief valve in the event that the load conditions change and cause a sudden increase in pressure Po. If the control piston is tracking the spool's movement, the flow control spool's return stroke may be slowed down. In certain situations, if the return pressure PR is higher than man Pf, the control piston may be forced back. The main piston then moves far more quickly than it would if the control piston were damping it. (Dong, Y. *et al*., 2023).

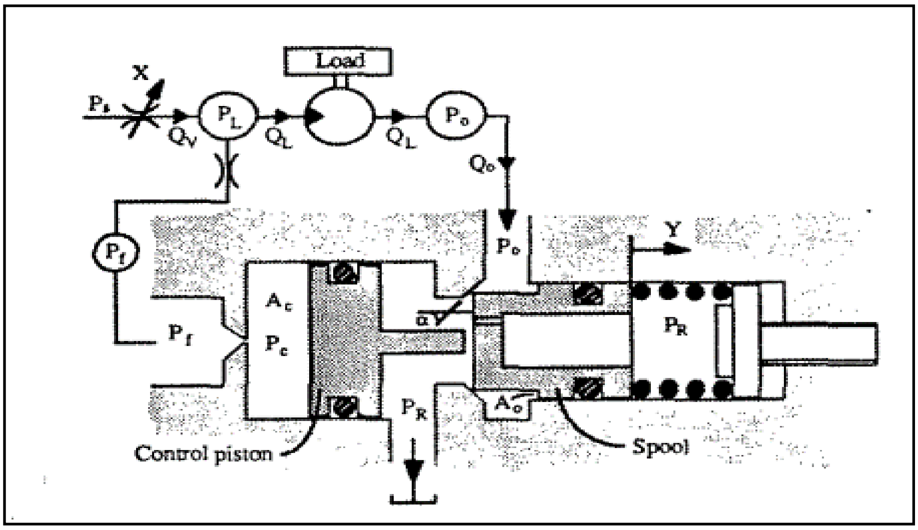

Fig. 1: System with the Actual Type of Over-Center Valve.

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Key Components of Over-Center Valves:
• Spool: The internal moving part that directs fluid to different ports.
• Spring: A component that returns the spool to the center position when not engaged.
• Seal: Prevents fluid leakage and ensures that the valve operates efficiently. (Liu, J. *et al*., 2024)
• Actuator: The device (manual, electric, hydraulic) that moves the spool to direct the flow.

Functional Design of Over-Center Valves
The designer of hydraulically operated machinery can now choose from a wide variety of over-center or motion control valves, each with a unique application and set of advantages for the user. These functions can be applied to either rotary or linear motion. (Yong, B. *et al*., 2021)

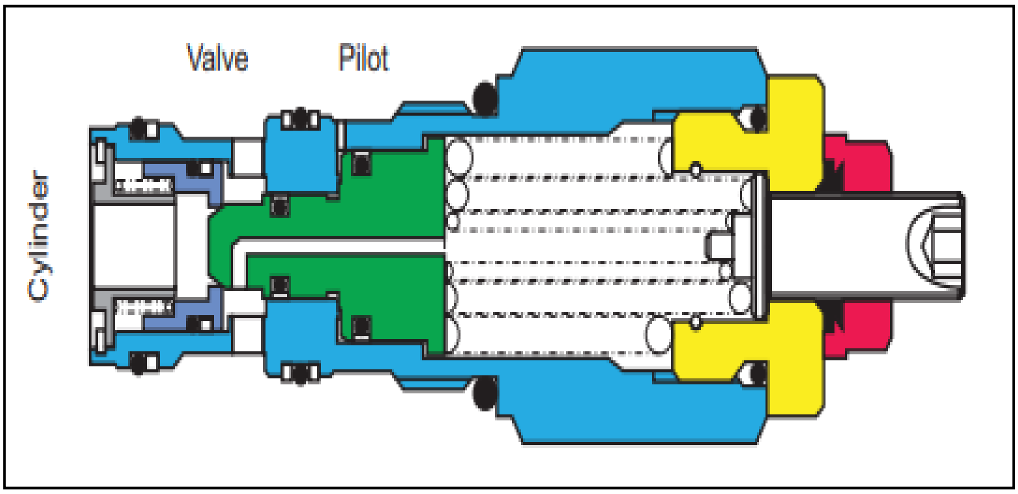

Fig. 2: Standard Over-Center Valve.

A typical over-center valve (Fig. 2) can be described as a pilot-assisted relief valve that incorporates a built-in free-flow check valve. Unlike a pilot check valve—where the check remains closed until pilot pressure overcomes the load pressure—the check in an over-center valve opens fully once the pilot pressure is sufficient to overcome the load-induced pressure holding it shut. In this configuration, the spring force must be countered by the pilot pressure, which is influenced by the load pressure. This mechanism ensures a smooth, gradual opening and controlled flow metering through the poppet. Over-center valves used in integrated hydraulic systems typically consist of three main components: a pilot section that regulates the poppet to allow controlled flow from the actuator, a check valve that enables unrestricted flow into the actuator, and a poppet that seals off reverse flow from the actuator (Yong, B. *et al*., 2021).

Various modifications exist for both fundamental over-center valve designs. For flow rates up to 200 L/min, the direct-acting type works best because actuator pressure is applied to the entire surface area of the poppet's nose. The differential-area design, on the other hand, is more appropriate for higher flow rates—up to 300 L/min—because it only exposes an annular portion of the poppet to pressure. Both designs provide outstanding sealing performance because of the poppet-style configuration. In particular, valves rated for 200 L/min can leak no more than 0.5 ml/min, whereas valves rated for 300 L/min can leak up to 4 ml/min (Khamkar, A. D., & Patil, S. M. 2024).

The cylinder port (1), valve port (2), and pilot port (3) are the three ports on the cartridge. The valve acts as a relief valve, opening to release excess pressure when the pressure at the cylinder port surpasses the valve's predetermined limit. On the other hand, a low-pressure check valve opens in response to pressure applied to the valve port, permitting unhindered flow into the cylinder port.

The pressure at the pilot port acts on a larger surface area of the poppet compared to the area exposed to the cylinder port, allowing the valve to open at relatively low pressure.

The relief pressure ought to be set roughly 1.3 times higher than the maximum load-induced pressure in the majority of applications. This guarantees that, absent pilot pressure, the valve will remain closed under maximum load conditions. The pilot ratio, or the ratio of the pilot area to the relief area, determines the necessary pilot pressure to open the valve. (Dong, Y. *et al*., 2023)

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It is possible to calculate the pilot pressure:

$$\text{Pilot pressure} = \frac{\text{Valve Setting} - \text{Load Pressure}}{\text{Pilot Ratio}}$$

The over-center valve is often mounted on the cylinder's end cap or inside (see fig. 3). Line B, which is the directional control line B and the annulus inlet, is connected to the pilot port. In the meantime, line A and the cylinder's full bore area are connected to the valve's cylinder port (Zhang, W., *et al.*, 2022).

Once the pressure at the annulus inlet port (line B) rises sufficiently to retract the rod and achieve the required pilot pressure, the actuator will begin moving at the flow rate determined by the pressure setting. If the load increases the flow demand, the inlet will eventually be depleted of oil, leading to a pressure drop at this port (Wang, Y. *et al*., 2022).

When the pilot senses the pressure drop, the spring begins to close the valve to prevent load runaway. During this movement, the valve continuously monitors and regulates the load. If the pressure required to move the load exceeds the pilot pressure needed to fully open the valve, the only restriction encountered is the pressure drop caused by flow through the fully open valve (Noskiević, P., & Walica, D. 2022).

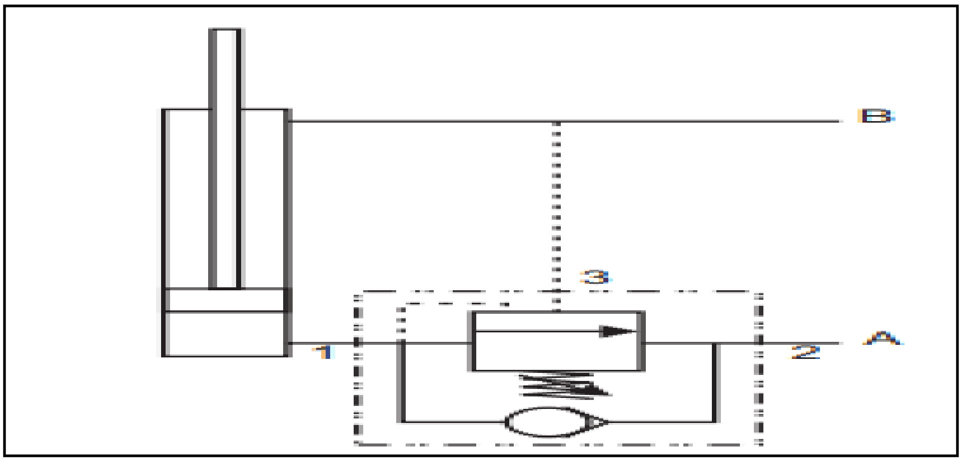

Fig. 3: The Over-Center Valve in or on the End Cap of a Cylinder.

In a conventional over-center valve, the spring chamber is vented to the valve port through the poppet, which can cause issues when back pressures fluctuate or rise. When pressure is present in the valve port, the valve's effective setting increases by a factor of the pilot ratio plus one. For example, if the pilot ratio is 5:1 and the back pressure is 50 bar, the effective relief setting would increase by 300 bar (Wang, Q. *et al*., 2023). This situation creates challenges in applications requiring a closed-center directional valve combined with the use of service line relief valves. While the relief valves control the inlet pressure, they do not respond to external loads that need limiting. Moreover, the over-center valve prevents oil flow past the seat due to the back pressure from the service line relief valves. To resolve this issue, the part-balanced design was developed (see fig. 5).

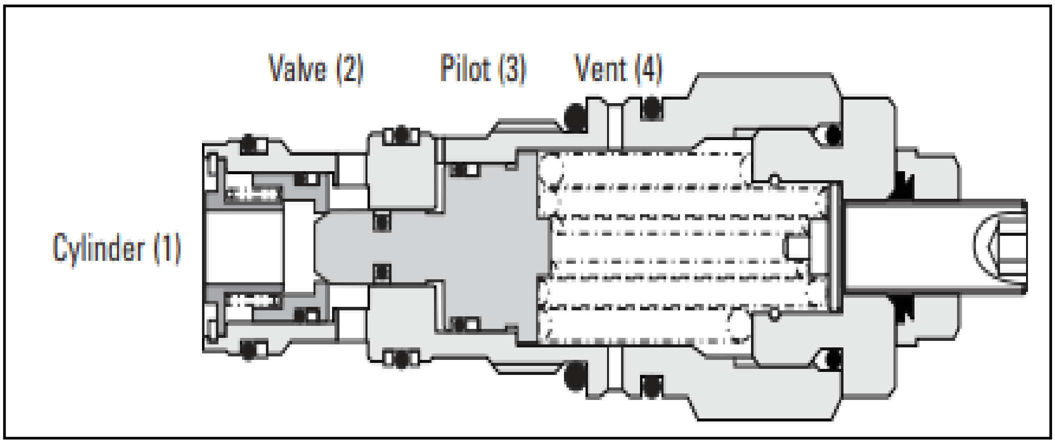

Fig. 4: Fully Balanced Over-Center Valve.

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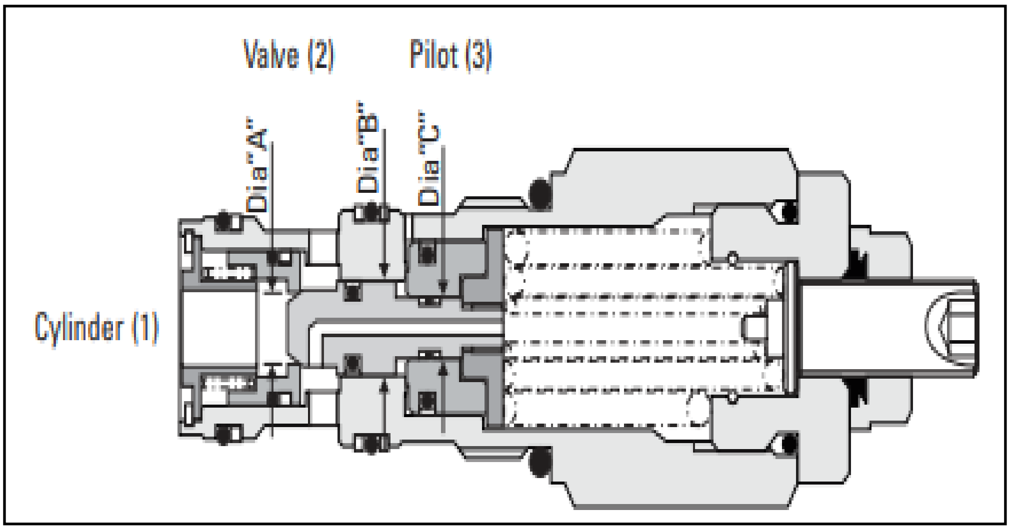

Fig. 5: Part Balanced Over-Center Valve.

Under most circumstances, the part-balanced over-center valve functions similarly to the standard valve. However, back pressure has no effect on the valve's relief section.

The purpose of the poppet is to distribute back pressure evenly across its two sections. The valve is opened by an annular region between the seat (dia a) and the center seal (dia b) on the poppet, and it is closed by an annular region at the spring end of the spool (dia c). Since these regions are identical, the poppet is balanced, and as a result, the valve's ability to provide relief will not be impacted by pressure in the valve line. It should be mentioned that any back pressure still has a one-to-one effect on the pilot pressure needed to open the valve. (Kikuwe, R. *et al*., 2021)

This design has the advantage of being able to be used on closed center directional valve systems, which permits service line relief valves to function normally. The atmospheric vent found in most other valves of this type that are on the market limits their use in corrosive settings and leaves them susceptible to leakage. (Liu, T., *et al*., 2024)

The part-balanced valve does have certain drawbacks in certain applications. Because the back pressure affects the pilot pressure, the valve cannot be utilized in regenerative circuits on the cylinder's annular port. Additionally, because of the constantly changing back pressures, the component balanced and the standard valve may become unstable if utilized with a meter-out proportional system. (Li, Z. *et al*., 2023)

For this reason, the fully balanced version (fig. 4) is introduced. In this design, the spring chamber is vented either to a separate drain port or directly to the atmosphere. Consequently, neither the required pilot pressure nor the valve’s setting is affected by any back pressure.

A range of pilot ratios is available to the system designer for standard, part-balanced, and balanced valves. Which one would be the best choice for his circuit?

Low pilot ratios work better with unstable and fluctuating loads, while high pilot ratios are generally appropriate for steady, constant loads. However, because the system's normal operating pressure is frequently much higher than the pilot pressure required to fully open the valve, the pilot ratio does not always have a significant effect on the working pressure. In these situations, the system's efficiency is mostly determined by the pressure drop that occurs when the valve is piloted open. (Wang, Y. *et al*., 2022)

Figure 6 shows the pressure drop curves for two valves with different pilot ratios. The valve with the higher pilot ratio exhibits greater restriction compared to the one with a lower pilot ratio. This suggests that beyond a certain pressure, the valve with the lower pilot ratio offers better performance. Therefore, the overall performance should be carefully considered when selecting an over-center valve. (Dong, Y. *et al*., 2023)

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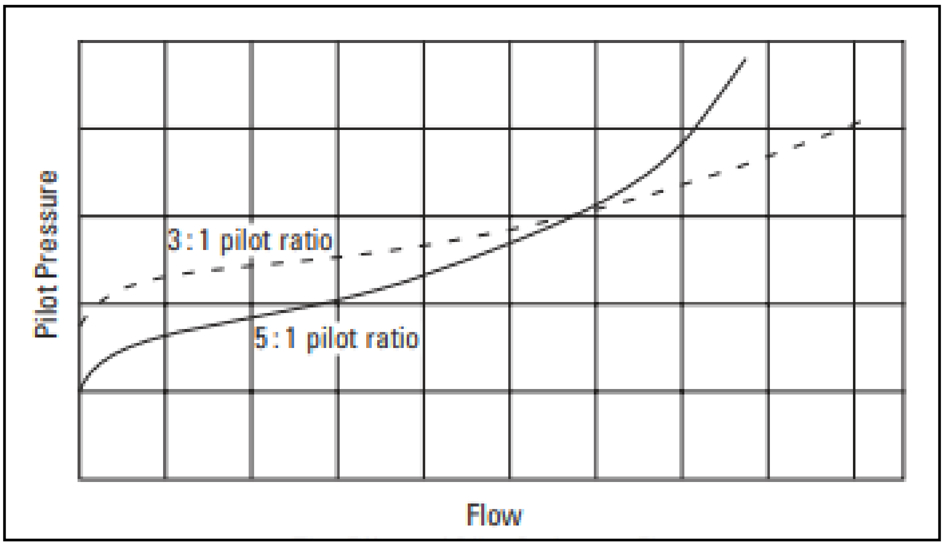

Fig. 6: The Effect of Pilot Ration on Flow.

THE IMPORTANCE OF OPERATING LIFE IN OVER-CENTER VALVES

Impact on System Performance

An over-center valve's operating life has a direct effect on a fluid control system's overall dependability and performance. Internal parts of the valve, like springs and seals, deteriorate with age, which has the following effects:

- Precision Loss: The valve may no longer precisely regulate fluid flow, which could cause actuator and cylinder movement to become unpredictable or uncontrollable. (Wang, Q. *et al.*, 2023)
- Increased Stress on Other Components: Pressure imbalances brought on by a malfunctioning valve may put additional strain on other system components, resulting in additional damage and decreased system performance.
- Higher Energy Consumption: In order to keep fluid flowing, worn valves frequently need more energy, which raises operating expenses.

Economic Considerations

It is far less expensive to keep a valve in good operating order than to replace it too soon. Increasing an over-center valve's lifespan has several financial advantages. It first reduces downtime because valve failures that halt operations can lead to costly production stoppages. By extending the valve's lifespan, businesses can avoid these expensive interruptions (Dong, Y. *et al.*, 2023). Second, regular maintenance reduces the need for costly repairs and replacements by preventing major issues before they occur. Last but not least, properly maintained valves ensure smoother operation and fewer unscheduled malfunctions, which ultimately lowers the long-term cost of ownership.

System Reliability and Safety

When over-center valves are used in hydraulic presses, cranes, and other industrial machinery, reliability is essential. Heavy machinery may move uncontrollably due to an unstable system brought on by a malfunctioning valve, which could lead to accidents or damage to the equipment (Liu, J. *et al.*, 2024). Furthermore, when valves malfunction in critical applications like lifting equipment, operators and employees run a serious risk of suffering severe injuries. Maintaining the integrity of these valves is essential to lowering these risks and ensuring that the system operates within the required safety margins.

FACTORS AFFECTING THE OPERATING LIFE OF OVER-CENTER VALVES

Material Properties and Valve Construction

The quality of the materials used in the construction of over-center valves has a significant impact on their longevity because their long-term performance is dependent on their capacity to tolerate wear, corrosion, and fatigue. Stainless steel is widely used because of its remarkable resistance to corrosion, especially in valves that are exposed to harsh environments. For applications requiring high temperatures and pressures, alloy steel is recommended due to its hardness and durability. Additionally, maintaining pressure control and preventing leaks depend on the quality of the elastomer and seal; however, over time, seals may deteriorate due to factors like fluid contamination, temperature changes, or pressure variations (Wang, Y. *et al.*, 2022).

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Operating Conditions

The operating environment is a critical determinant of the lifespan of over-center valves because a variety of factors can significantly affect their longevity. Operating at or near the maximum rated pressure can hasten wear and result in an earlier failure because the internal components are constantly under a lot of stress (Yong, B. *et al*., 2021. Similarly, increased flow rates can accelerate internal component wear by increasing friction and heat production within the valve (Noskiević, P., & Walica, D. 2022). The performance of valves is also affected by temperature extremes; very low temperatures can cause parts to become brittle and more likely to crack, while high temperatures can weaken seals and reduce the valve's ability to maintain pressure.

Fluid Quality

The longevity of the valve is significantly impacted by one of the most important factors affecting the fluid quality used in the system. Contaminants such as dirt, water, or metal particles can drastically reduce the lifespan of internal valve components. Additionally, to prevent issues like cavitation or valve malfunction, the fluid's viscosity must be maintained within the recommended range. To protect the valve, suitable filtration systems must be installed to control contamination and prevent impurities from entering the fluid. Furthermore, because too high or low viscosity levels can hinder the valve's ability to effectively regulate flow, fluid viscosity is essential to valve performance (Processes, 2023).

Valve Design and Size

The over-center valve's ability to withstand operational stress is significantly influenced by its size and design. Due to their higher load-bearing capacity, larger valves can generally tolerate higher pressures and flow rates with less wear than smaller valves (Ribout, M. *et al*., 2023). Selecting a valve that is either too large or too small for a given application may lead to premature wear, a reduced lifespan, and inefficient operation. Additionally, balanced valve designs increase overall durability and reduce stress on individual components by more evenly distributing internal forces, thereby prolonging the valve's lifespan.

MAINTENANCE PRACTICES TO EXTEND VALVE LIFE

Routine Inspections

Routine inspections are essential to identifying early signs of valve wear and preventing unscheduled failures. Operators should regularly check the outside of the valve for visible wear indicators like corrosion or cracks. It's also important to pay close attention to any fluid leaks that may occur close to joints and seals. Performance testing under different loads and pressures is also necessary to ensure the valve continues to operate as intended (Wang, Y. *et al*., 2022).

Lubrication and Seal Maintenance

Proper lubrication is essential for valves to continue functioning smoothly. By lowering friction between moving parts, lubricants help to reduce wear and avoid overheating. Additionally, routine seal maintenance is essential:

- Seal Inspection: Inspect seals for cracks, hardness, and leaks, and replace them as needed.
- Lubrication Schedule: Follow the manufacturer's recommendations for lubrication intervals to prevent friction and seal deterioration.

Monitoring and Adjusting Operating Parameters

The longevity of the valve depends on making sure it operates within the designated range of pressure, flow rate, and temperature. Operators should:

- Check Pressure: Make sure the valve isn't exposed to pressures higher than what is advised by using pressure gauges. (Zhang, W., *et al*., 2022)
- Control Flow: To prevent overstressing the valve, modify flow rates as necessary.

Proactive Replacement of Worn Components

It's critical to replace worn-out parts like seals, springs, or spools before they cause serious problems. Preventing unforeseen malfunctions and maintaining the system's functionality can be achieved through proactive replacement. (Jaiswal, S. *et al*., 2024)

SIMULATING USING FLUIDSIM

To explain the necessity of over-center valves, an inverted pendulum serves as an excellent example, as shown in (fig.7). Here, a cylinder is attached to the pendulum, with a load mounted at its end. Retracting and extending the cylinder enables the pendulum to swing forward and backward. To push the pendulum from one end to the other during its ascent, the cylinder acts against both the load and gravitational forces. Thus, the pendulum is perpetually controlled by the pump driving the load.

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When the pendulum passes its center of gravity and begins descending, the load becomes unbalanced, causing the pendulum to accelerate faster than the cylinder's movement. At this stage, the load drives the pump, as both the load and gravity align with the cylinder's motion. An over-center valve regulates cylinder movement by metering flow from it, thereby continuously controlling the load. (Kikuwe, R. *et al*., 2021)

Since this scenario repeats in reverse, a second over-center valve is required on the opposite line. Hence, a dual over-center valve is employed to regulate flow from both ends of the cylinder (fig8).

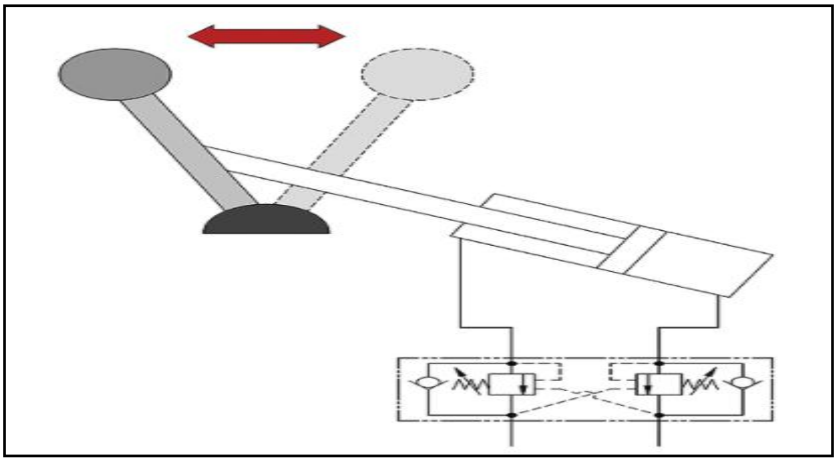

Fig. 7: A Hypothetical Inverted Pendulum Demon-Strating the Need for an Over-Center Valve.

Dual over-center valves are also critical in track wheels of heavy earthmoving machinery (Fig. 9), where equipment must traverse steep slopes. The machinery must operate directionally on inclines. When moving forward downhill or reversing uphill, the machine tends to roll uncontrollably. Dual over-center valves connected to hydraulic motors prevent load runaway by controlling oil outflow in both directions. However, a parking brake remains mandatory for swing drives. (Jaiswal, S. *et al*., 2024)

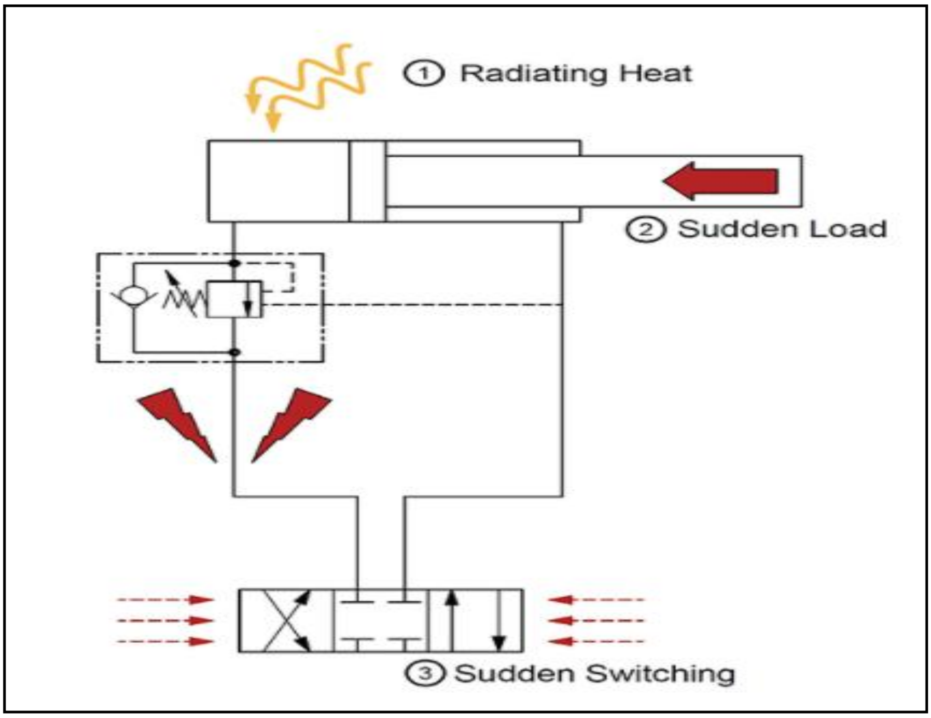

Fig. 8: Lock valves must never connect to blocked center directional valves. Sudden centering of the spool (l) or pressure spikes from fluid temperature rise (2) trap fluid, risking hose rupture, equipment damage, or operator fatality.

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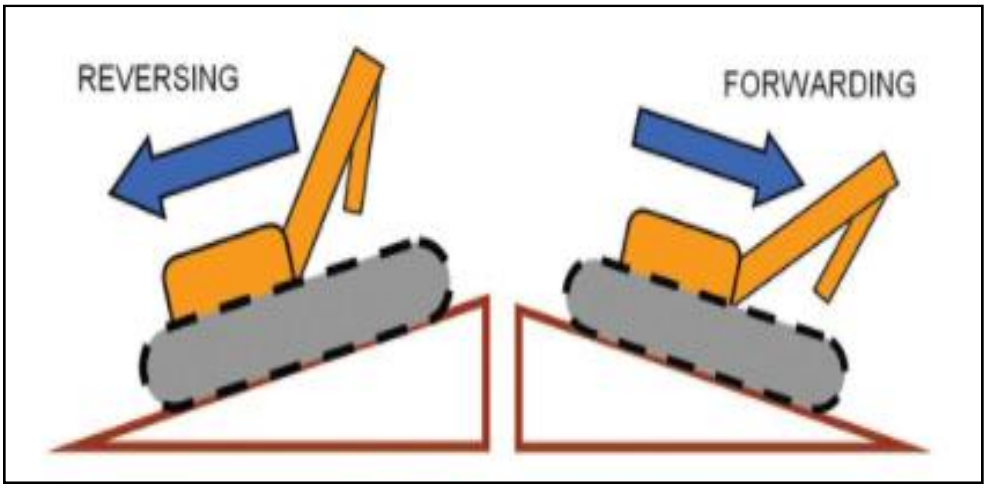

Fig. 9: Mobile equipment on slopes may lose control due to inadequate track wheel management. Reversing uphill or moving forward downhill can cause load runaway.

Hydraulic Circuit Simulation in FluidSIM

For the selected control schematic, we simulated the impact of hydraulic system (HS) parameters on cylinder (HC) motion using FluidSIM.

We modeled a hydraulic system consisting of a pumping station connected to a directional valve to change the direction of movement of the hydraulic cylinder. We applied a load of 25,000 N to it, which changed midway through the path to -25,000 N. We added a double over-center valve between the cylinder and the directional valve. We then calculated the changes in position (mm), velocity (mm/s), acceleration (mm/s^2), and load (N).

In the first simulation, the hydraulic fluid exits the pumping station at a working pressure of 100 bar through the directional valve, moving the cylinder, which is subjected to a load of 25,000 N, to the right. We note that the fluid pressure exiting the cylinder is 80 bar, heading towards the tank. In this case, the over-center valve does not intervene (fig. 10).

At the midpoint of the stroke, the load suddenly changes to -25,000 N, causing the cylinder rod to be pulled towards it. Here, the over-center valve intervenes and prevents the load from pulling the cylinder rod. This is clearly evident when the pressure at the cylinder outlet rises to 157 bar (fig. 11).

After passing the shock of the load change, the cylinder continues to move until the end of its path (fig. 11).

When the directional valve is changed to return the cylinder to its position, the pressure in the annular region is 40 bar and the pressure outside the cylinder towards the tank is close to zero without the intervention of the over-center valve (fig. 12).

The process continues until the load changes from -25,000 N to 25,000 N. Then, an over-center valve intervenes and prevents the load from pushing the cylinder uncontrollably. This is clearly evident when the pressure at the cylinder outlet rises to 61 bar. After overcoming the shock of the load change, the cylinder rod continues its path until the end (fig. 13).

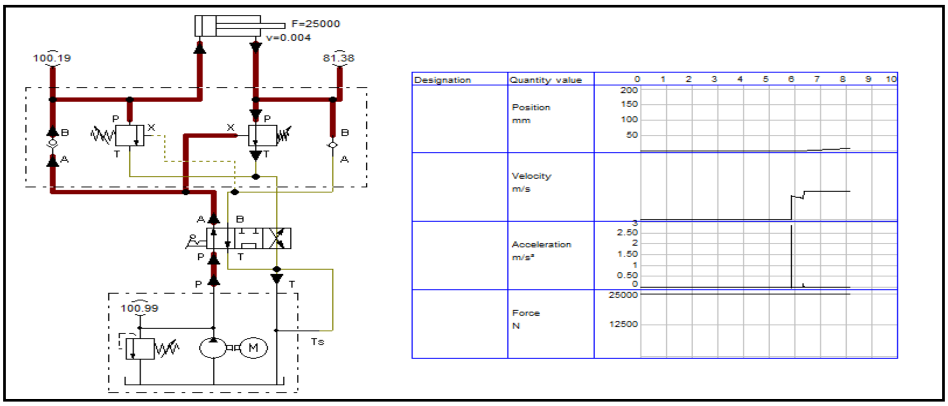

Fig. 10: Simulation 1 case 1 load 25000N.

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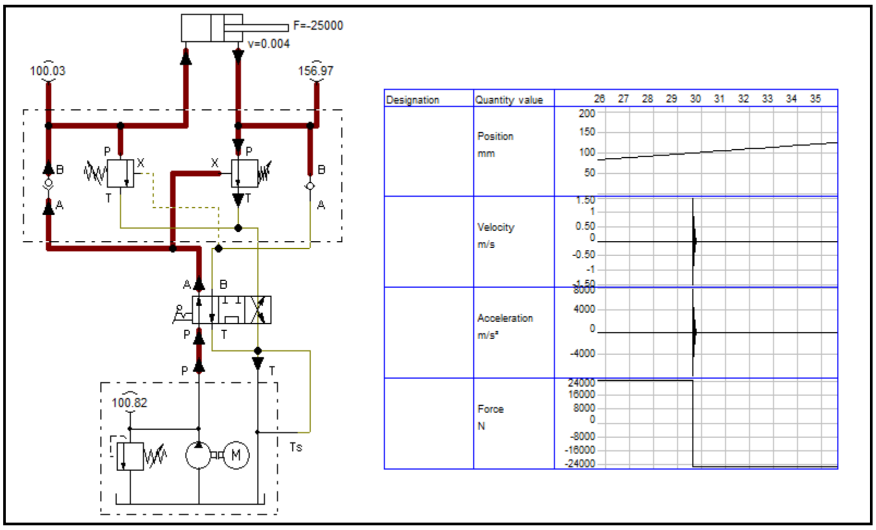

Fig. 11: Simulation 1 case 2 load from 25000N to -25000N.

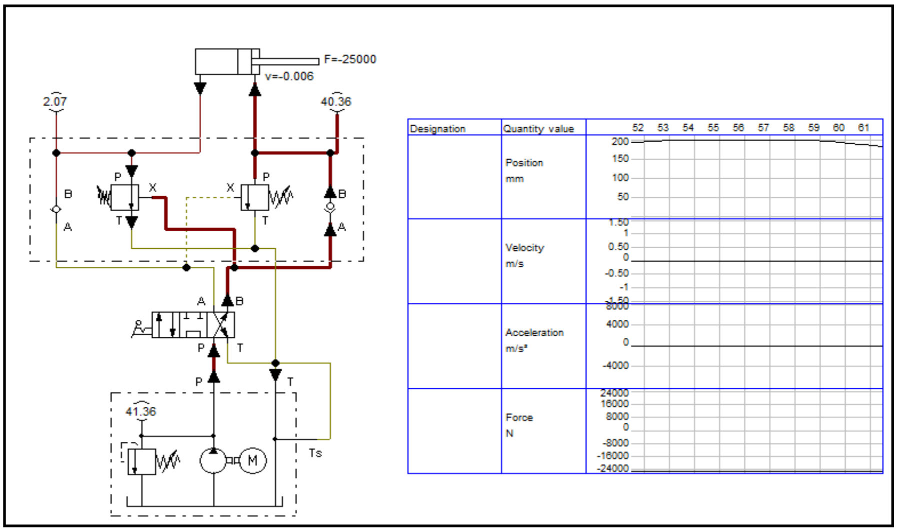

Fig. 12: Simulation 1 case 3 load -25000N.

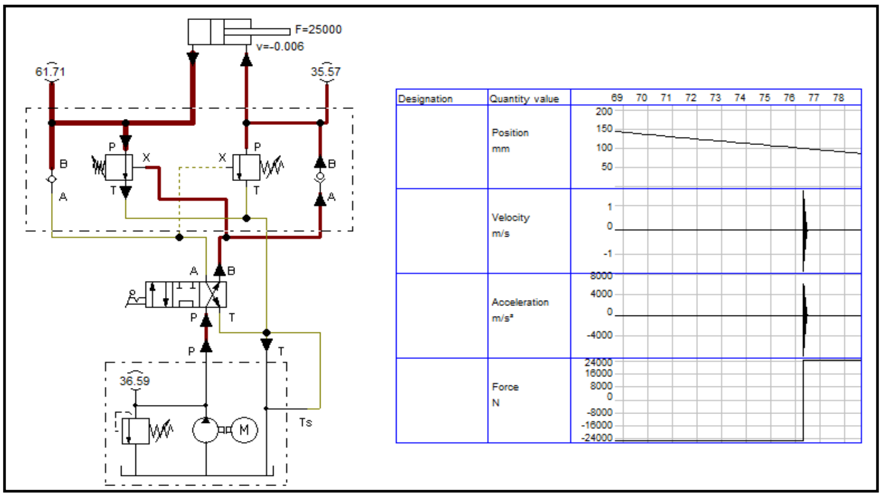

Fig. 13: Simulation 1 case 4 load from -25000N to 25000N.

In the second simulation, the hydraulic fluid exits the pumping station at a working pressure of 50 bar through the directional valve, moving the cylinder, which is subjected to a load of 25,000 N, to the right. We note that the fluid pressure exiting the cylinder is 22 bar, heading towards the tank. In this case, the over-center valve does not intervene (fig. 14).

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At the midpoint of the stroke, the load suddenly changes to -25,000 N, causing the cylinder rod to be pulled towards it. Here, the over-center valve intervenes and prevents the load from pulling the cylinder rod. This is clearly evident when the pressure at the cylinder outlet rises to 97 bar (fig. 15).

After passing the shock of the load change, the cylinder continues to move until the end of its path (fig. 15).

When the directional valve is changed to return the cylinder to its position, the pressure in the annular region is 52 bar and the pressure outside the cylinder towards the tank is close to 10bar without the intervention of the over-center valve (fig. 16).

The process continues until the load changes from -25,000 N to 25,000 N. Then, an over-center valve intervenes and prevents the load from pushing the cylinder uncontrollably. This is clearly evident when the pressure at the cylinder outlet rises to 74 bar. After overcoming the shock of the load change, the cylinder rod continues its path until the end (fig. 17).

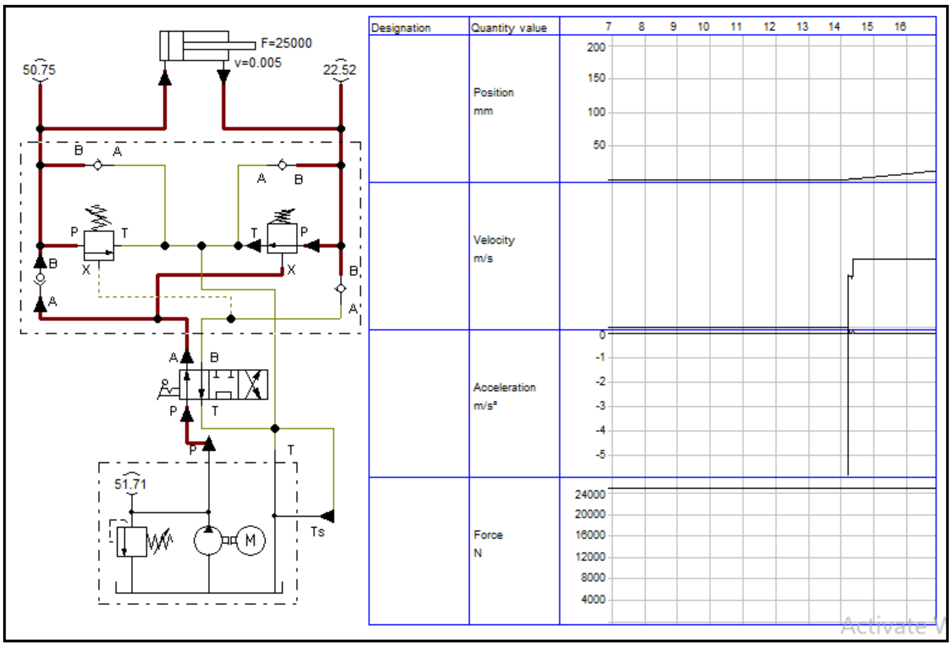

Fig. 14: Simulation 2 case 1 load 25000N.

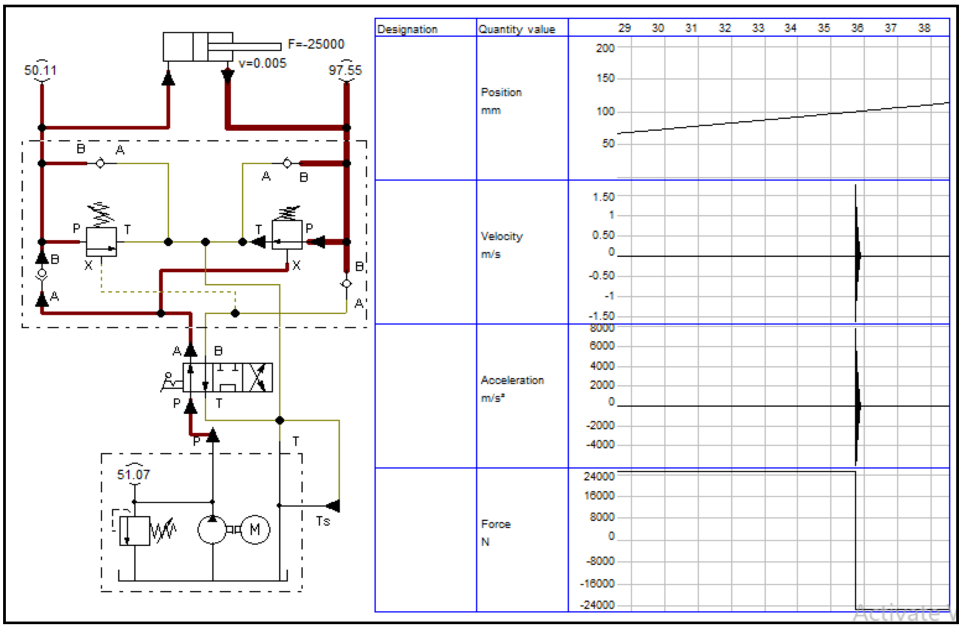

Fig. 15: Simulation 2 case 2 load from 25000N to -25000N.

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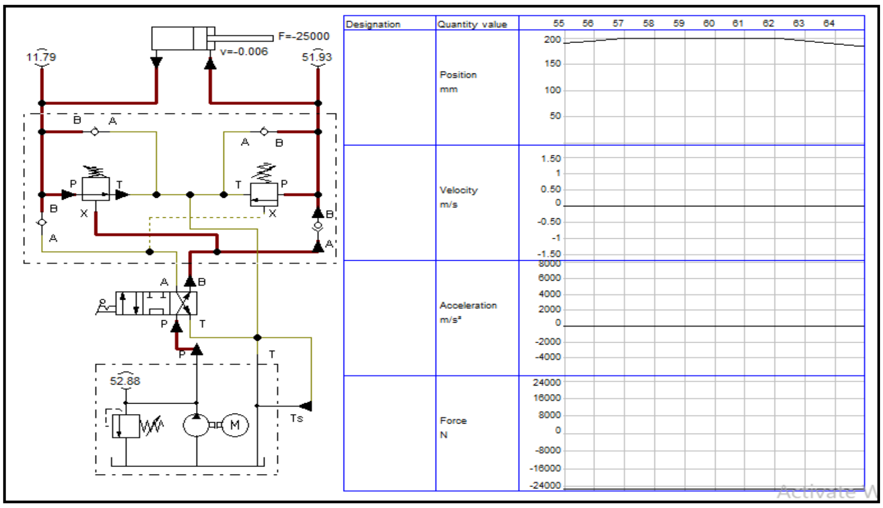

Fig. 16: Simulation 2 case 2 load -25000N.

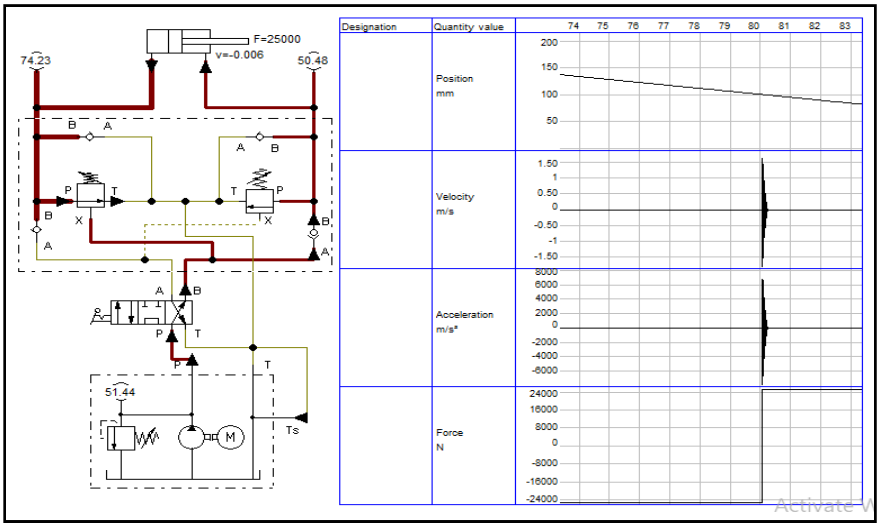

Fig. 17: Simulation 2 case 2 load from -25000N to 25000N.

CONCLUSION

The operating life of over-center valves is influenced by a combination of factors, including material quality, operating conditions, fluid cleanliness, and maintenance practices. By understanding these factors and implementing strategies for monitoring and maintaining the valve, businesses can significantly extend its service life, ensuring optimal performance, reliability, and safety in their operation.

In the first and second simulations using FluidSIM software, the performance of the over-center valve was observed in resisting dynamic load changes, its instantaneous response (0.2 seconds), and controlling sudden load increases (100% greater than the applied load)while maintaining constant process speed and acceleration.

Notation (TNR, Size 12, Bold, line spacing 1) Space Size 12

P_L the load pressure
P_R the return pressure
P_o the pressure downstream the motor
P_f the force pressure
HS hydraulic system
Hc hydraulic cylinder

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