Designing With Cylinders Telescopic Cylinders

The great advantage telescopic cylinders have over conventional rod-type cylinders is their ability to provide an exceptionally long stroke from a compact initial package. The collapsed length of typical telescopic cylinders varies between 20% to 40% of their extended length. Thus, when mounting space is limited and the application needs a long stroke, a telescopic cylinder is a natural solution.

For example, a dump body needs to be tilted 60 degrees in order to empty completely. If the body or trailer is fitted with a conventional rod-type cylinder - with a one-piece barrel and stroke long enough to attain that angle - the dump body could not return to a horizontal orientation for highway travel because of the cylinder’s length, even when fully retracted. A telescopic cylinder easily solves this problem.

Telescopic hydraulic cylinders are relatively simple devices, but their successful application requires an understanding of this component's idiosyncrasies. Knowledge of how telescopic cylinders work and which special application criteria to consider will enable you to design them safely and economically into equipment.

Main and Stages

As the name infers, Telescopic cylinders are constructed like a telescope. Sections of DOM (drawn over mandrel) steel tubing with successively smaller diameters nest inside each other. The largest diameter section is called the main or barrel; the smaller-diameter sections that move are called stages; The smallest stage is also called the plunger. The maximum practical number of moving stages seems to be six. Theoretically, cylinders with more stages could be designed but their stability problem would be daunting.

Telescopic cylinders normally extend from the largest stage to the smallest. This means the largest stage - with all the smaller stages nested inside it - will move first and complete its stroke before the next stage begins to move. This procedure will continue for each stage until the smallest-diameter stage is fully extended. Conversely, when retracting, the smallest-diameter stage will retract fully before the next stage starts to move. This continues until all stages are nested back in the main.

Basic Cylinder Types

As with conventional cylinders, the two basic types of telescopic hydraulic cylinders are single- and double-acting.

Single-acting telescoping cylinders extend under hydraulic pressure and rely on gravity or some external mechanical force for retraction. Single-acting cylinders are used in applications where some form of load is always on the cylinders. The classic single-acting telescopic applications are dump trucks and dump trailers. Pressurized oil extends the telescopic cylinder to raise one end of the dump body and expel its load. When pressure is released, the weight of the dump body forces oil out of the cylinder and it retracts.

Double-acting telescopic cylinders are powered hydraulically in both directions. They can be used in applications where neither gravity nor external force is available. They are well suited to noncritical positioning applications requiring out-and-back movement of a substantial load. A classic application is the packer-ejector cylinder in refuse vehicles and transfer trailers. The horizontally mounted cylinder pushes a platen to compress the load, then must retract with the platen so more material can be added. Gravity cannot help, so a double-acting cylinder is used.

Bearings and Seals

Each stage is supported within each successively larger stage by at least two bearings. One is at the bottom outside diameter or piston end of the stage, and the other is at the top internal diameter or packing section of the next larger stage. The distance between these two bearings determines the degree by which one stage overlaps the next. Generally, this distance or overlap must increase as overall stroke increases in order to resist deflection caused by the weight of extended stages and the load.

There are several designs for sealing telescopic cylinders. One of the most common designs for sealing telescopic cylinders is the use of several hinged chevron vee seals and / or one-piece, multi-lip seals with hinged lips molded in place. These seals are held in place by a stop ring or snap ring and packing nut and they use guide bearings on the sleeve piston. The internal diameter “ID” of each stage is sealed against the outer diameter “OD” of the next smaller stage nested inside it. The style and placement of these seals varies among cylinder manufactures. The style of seal also depends on its particular function. Zero-leakage, multiple-lip soft seals are usually found in the internal diameter at the packing section of the main and moving stages. Low-leakage hard seals are found on the piston end of double-acting telescopic cylinders. These piston seals allow the cylinder to retract under pressure.

Another design used on some single-acting telescopic cylinders, is the use of soft, zero leakage seals on the piston, which in turn use the full bore of the next larger stage as the effective area for extend force. These same seals contain the oil in the cylinder. The upper end of the cylinder, where the soft seals normally would be found, now contains a bearing for guidance. If any type of seal is used in the upper end of this telescopic cylinder design, it is usually a wiper/seal combination to exclude contaminants from entering the cylinders. With either type, the many sealing surfaces must compensate for normal deflection of stages as the cylinder extends.
The cylinder design with the bearing on the piston and the seal on the other end is called a *displacement-type cylinder*. The single-acting design with a seal on the piston and a bearing at what normally would be the packing end approaches the classification of ram-type cylinder. Performance is similar to a double-acting rod-type cylinder with pressurized oil being supplied only to the piston side. All the telescopic stages would stroke in this way.

**Double-Acting Telescopic Cylinders**

Normally extension of a double-acting telescopic cylinder occurs in the same manner as with the single-acting type.

Retraction of double-acting telescopic cylinders is made possible by sealing each moving stage’s piston area outside diameter with the next larger stage’s inside diameter and building internal oil-transfer holes into each moving stage. The oil-transfer holes are located just above the pistons in the body of the stage. The retraction port normally is located in the top of the smallest stage. Oil flows through this port and into the smallest stage. The oil-transfer hole allows oil to enter and pressurize the volume between the next stage’s internal diameter and the smaller stage’s outer diameter. Pressure in this volume generates the force to move or retract the smaller stage into the larger stage.

Once this stage is fully retracted, the oil-transfer hole in the next larger stage is exposed to allow oil flow for it to retract. This retraction process continues automatically until all stages have retracted into the main. The seal on each stage selects the areas against which pressure will work.

Locating the retract port on the top of the smallest stage is the simplest way to design a double-acting telescopic cylinder, but this port location typically requires an arrangement of hoses, hose protection, and hose reels to deliver oil to the moving stage. To avoid having fluid power ports spaced far apart when the cylinder is fully extended, most double-acting telescopic cylinder designs locate both fluid ports in the smallest stage or plunger. The cylinder is then mounted so that the smallest stage or plunger is stationary and the larger and heavier stages would be the ones that move as the cylinder extends.

In some instances a double-acting telescoping cylinder can be designed where both ports are located in the stationary main barrel. Cylinder size (diameter and stroke) and the number of moving stages determine whether this is possible. If it is, the more-complicated internal passages for oil flow require a double wall and or a special trombone type telescopic design.

Piston seals on double-acting telescoping cylinders are normally manufactured from a hard substance such as cast iron, ductile iron or glass-reinforced nylon. The hard seals are needed to limit abrasion between the oil transfer holes and ports over which they must pass.

**Single- and Double-Acting Combinations**

There are a few unusual types of telescoping cylinders designed for specific applications. For example, a manufacturer of oil well equipment uses a type composed of both single- and double-acting stages to position a work-over rig. The work-over rig is a derrick or tower that is transported horizontally to the well site on a trailer. There, telescopic cylinders extend to swing the rig into a vertical position. When the rig’s work is done, the telescopic cylinder pulls the rig to begin the transition from vertical back to horizontal. However, once the rig has started to tilt, no more pull force is needed because of the rig’s weight and gravity will continue to retract the cylinder. In other words, the cylinder needs hydraulic power for the first part of its retraction stroke, but then operates as a single-acting unit.

In this type of design, the smallest moving stage is designed to be double-acting; the others are single-acting. The small stage can then provide push force to raise the rig, and pull force to start it back down. It is not unusual to design this type cylinder as a skip-a-sleeve design. Skip-a-sleeve design is as it’s name implies, a sleeve or stage is skipped during design. Normally a telescopic stage diameter increases approximately every inch, example; sleeve diameter may be 3.75” fits into a 4.25” bore, 4.75” fitting into 5.25” bore, etc. In a skip-a-sleeve design, a sleeve is removed to increase the effective area and the retract force of the smallest sleeve or plunger, example; plunger diameter is 2.75” and fits into the 4.25” bore of the 4.75” sleeve, thus increasing effective area and retract force.

**Constant-Thrust / Constant-Speed**

A special telescopic cylinder - known as a constant-trust/constant-speed cylinder - is configured so that all moving stages will extend at the same time, providing an overall constant speed as well as a constant push force throughout its stroke when extending or retracting. This type of cylinder has been used to drive a drill head in underground mining, where such performance parameters are necessary and space is at a premium. The more-complicated design accomplishes the required action by trapping oil internally, matching extend and retract areas, and limiting the number of moving stages.
Design Considerations

Three familiar formulas determine the general operating characteristics of telescoping cylinders and can be manipulated to calculate the cylinder size required for a given cycle time or load. These formulas are:

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\begin{align*}
F &= A \times P \\
S &= 19.2 \frac{Q}{A} \\
T &= \frac{V}{231Q}
\end{align*}
\]

where:

- \(F\) - force, lb
- \(S\) - speed, fpm
- \(T\) - cycle time, min
- \(A\) - area, in\(^2\)
- \(Q\) - flow rate, gpm
- \(V\) - cylinder volume (area \(\times\) stroke), in\(^3\)
- \(P\) - operating pressure, psi

The basic formulas for force, speed, and cycle time that apply to conventional rod-type cylinders also can be used with telescopic cylinders. To successfully apply these formulas, the designer must know which of the multiple areas and diameters to use. To calculate the force of any stage, you must decide which area will be substituted into the formulas. This area is determined by the placement of the seals that describe the boundaries of the area. For example: the extend area of a double-acting stage is determined by the seals on the pistons. Thus, the appropriate area would be calculated from the internal diameter of the next larger stage. On retraction, the area of any double-acting stage is the difference between that stage’s outside diameter and the inside diameter of the next larger stage.

Designers must remember that the extend area for each stage is different, so the extend force for each stage also is different. The differences in areas mean that in an application with a constant-displacement pump supplying the hydraulic system, each stage will move at a different speed. This speed difference for each stage also holds true during retraction of double-acting telescopic cylinders because each stage’s retract area is different.

In both types of telescopic cylinders, the smallest stage determines the force capacity of the cylinder. This stage will usually have the smallest extend and retract area. During extension, this stage will generate the cylinder’s minimum force; during retraction, this stage normally generates the maximum force. A double-acting telescopic cylinder can exert no more retraction force than the smallest retract area provides.

After determining the effective diameter of each stage, volume can be approximated by dividing stroke by the number of stages and multiplying the quotient by each effective area. The sum of these volumes equals the approximate volume of oil to extend the cylinder. Reservoir volume should equal the cylinder’s extended volume plus an initial volume of oil to fill the fully retracted cylinder and an adequate reserve for make-up oil.

Pump capacity is determined by applying the formula for speed to solve for \(Q\) (flow rate, gpm) in each stage. Inlet porting at the cylinder must be sized to accommodate the required flow for a given extension speed, of course.

Special Design Considerations

Designers should never treat the telescopic cylinders as structural members. These cylinders should be used to generate work forces - not to stabilize the structure. They should be considered no more rigid than the columns of oil they contain. Telescopic cylinders always should be provided with mechanical support members.

Fully extended, long stroke telescopic cylinders can become very long, slender columns, making them susceptible to buckling. The structure of a telescopic cylinder can be considered as special as a stepped column with different diameter elements, each having a different moment of inertia. Additional overlap can help stabilize such a cylinder, but more overlap increases collapsed length as well as overall column length. Sometimes a cylinder diameter larger than required for the load may be needed to keep the cylinder safe under column loading.

As stated earlier, single-acting telescopic cylinders are extended by pressure and retracted by gravity or an external force. The extend speed is determined by the pump flow and flow capacity of the control valve. The retract speed is a function of the load on the cylinder and the ability of the hydraulic fluid to return to tank. Retraction speed can be controlled by metering return-oil flow through the control valve. Light loads and restricted flow slow down the retraction stroke. Most single-acting telescopic cylinders will not retract under their own weight. This is a result of several variables, including friction of the internal seals, attitude of the cylinder, and the type of mounting. A rigid mount with a low attitude may cause enough binding so that light loads cannot force the cylinder to retract.

As with any type of cylinder, heavy side loads should be avoided. Because of telescopic cylinder’s multiple moving stages, side loading can cause internal binding that could result in mis-staging and possible stalling of the cylinder’s movement. Because the overlap of each successive stage must be designed and manufactured with running and machining tolerances, these areas can act like hinges, allowing some movement. Longer overlap helps limit this movement, but cannot eliminate it. This is a Catch 22 design situation: the longer the overlap, the longer the cylinder’s collapsed length.
Flow, Pressure Control

A three-way, three-position valve can provide raise, lower and hold control for a single-acting cylinder. Retraction speed of single-acting cylinders may be controlled by manually metering flow through the valve’s return port. As an alternative, some systems use an orifice in the return line, valve, or cylinder port that is sized to limit flow and, thus, limit retraction speed.

Four-way, three-position valving is needed to perform the same control functions on double-acting types. The additional pathway provides a route to tank for oil displaced from the plunger end.

Dealing with Intensification

Due to its construction, double-acting telescopic cylinders will act as pressure intensifiers during extension and flow multipliers during retraction. These two phenomenon are directly related to the large difference in effective area between the extend and retract side of each stage piston. This ratio can be as high as 10:1, or even greater. During extension of a double-acting telescopic cylinder, hydraulic oil is pumped into the extend port and exhausted out the retract port. If exhaust flow is impeded or restricted, the retract side of the cylinder can be pressurized to a level equal to the extend pressure multiplied by the differential area ratio. A dead block of exhaust flow can produce pressures high enough to destroy the cylinder. If any type of holding or check valve is installed in the retract line or on the retract port, the pressure intensification phenomenon can become dangerous. In the case of a 10:1 stage, a 2000 psi main pressure would result in an intermediate plunger pressure of 20,000 psi if flow from plunger is dead blocked. A similar, though less hazardous condition often results when the plunger side outlet line is reduced for design reasons or as the result of clogging or misconnection. The circuit must be designed so that these valves open before (or simultaneously with) the application of extend pressure to the cylinder.

When a double-acting cylinder retracts, the opposite occurs. Oil is pumped into the retract port and exhausted through the extend port. The exhaust flow will be equal to the retract flow multiplied by the differential area ratio. With a 10:1 ratio, a 20-gpm retract flow becomes a 200-gpm exhaust flow. If the extend lines or valves are too small and flow is restricted, backpressure can occur in the cylinder to slow the retract speed. If the backpressure equals the pump’s retract pressure, the cylinder will stall and not retract.

Telescopic cylinder manufacturers attempt to size the ports to eliminate or reduce the potential for this phenomenon, but designers should size other components in the hydraulic circuit with this in mind. Most problems relating to these phenomenon result from increasing pump flow or downsizing lines, connectors, or control valves after the cylinder has been specified for operation with larger components.

Seal Bypass

Piston seals in double-acting telescopic cylinders normally are manufactured from a hard substance, such as cast iron, ductile iron, or glass reinforced nylon. Hard seals are needed to resist abrasion when the seals slide across the transfer holes. However, these seals are not as efficient as soft urethane or rubber seals, so small amounts of oil can bypass them. This bypass flow actually can cause a cylinder to stall if pump flow is less than the seal’s allowable leakage rate. This may become a problem if the cylinder is required to stroke at low speeds. Consequently, loading should be limited to a level slightly below the cylinder’s rated force at a given pressure.

Bypass leakage also can allow a cylinder to drift in either direction while holding a load. Drift is extremely hazardous if the cylinder is holding a load on the retract area. If a piston drifts past the internal transfer holes in a stage, the retract oil will rapidly transfer to the extend area - causing the cylinder to extend abruptly. This is possible because the retract oil volume is less than the extend volume, due to the large differential area ratio. Therefore, a double-acting telescoping cylinder should not be expected to hold a load on retraction.

Summary

It should now be evident that specifying telescoping cylinders requires knowledge beyond that of conventional cylinders. The best insurance to guard against unforeseen problems — especially for those lacking familiarity with telescoping cylinders — is to draw from the experience of manufacturer’s application engineers.

Manufacturer’s of telescopic cylinders can (and have) altered their designs to suit a variety of special application considerations. Their application engineers should be eager to provide assistance in selecting or designing the right cylinder for your specific application, and advising about circuitry to operate it safely and efficiently.