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WEST VIRGINIA UNIVERSITY
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HYDRAULIC CYLINDER

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AGRICULTURAL EXPERIMENT STATION

THE AUTHOR

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HYDRAULIC cylinders are used extensively wherever linear motion with high force and low velocity is required. This requirement was encountered in designing an experimental hay drier where a linear motion through a distance of about five feet was needed. Desired forces were estimated to be around 5,000 pounds, to be applied on the end of a bale of hay.

Various mechanical devices were considered but all were either too cumbersome or interfered with the working space near the bale of hay. Room was available for a long cylinder, and cost estimates were obtained for a suitable commercial cylinder. These were considered excessive for the job. The cylinders were also excessively heavy for convenient handling. Assuming that other researchers must have similar needs, the following objectives were established for building a cylinder in the laboratory: (1) light weight, (2) low cost, (3) the capacity to produce the desired forces through the required distance, and (4) a reasonable life expectancy but which could be a much shorter use period than normally specified for commercial cylinders.

Cylinders for Agricultural Applications

Most modern tractors have built-in hydraulic systems. These operate a special cylinder or cylinders integral with the tractor. Many systems have connections to operate a remote cylinder. The cylinders integral with the tractors have adequate production volume and use to justify special designs and honed finishes. The remote cylinders frequently have limited use on any one machine, due to seasonal operations, and are built in two standard sizes so that one cylinder may be used in numerous places. This justifies a more expensive cylinder and reduces costs due to the greater volume of production.

The two sizes have 8 inch and 16 inch strokes with extended lengths of 28.5 inches and 47.5 inches and such diameters that the rate of operation is within specified limits. Thus, a remote cylinder for a tractor with a hydraulic pump having a given volumetric displacement would not be interchangeable with a tractor having a hydraulic pump with a considerably different volumetric displacement. Most machines that need hydraulic controls can be designed to comply with these standard cylinders. Low cost special cylinders would find additional uses where the standard cylinders will not fit into a design. Also, these cylinders could open a new area for farm mechanization in which a tractor is not involved. Equipment integral with a structure is one area where this would apply.

Industrial Applications

Hydraulic cylinders of almost any size and shape can be found in various industrial uses. These have honed working surfaces. Frequently the working surfaces have noncorrosive and hardened platings which contribute to the long life of the cylinder. Special molded packings are used in conjunction with these excellent finishes with the result of trouble-free performance for millions of cycles. These fine finishes are very expensive, but quite desirable where continued use makes them economically feasible. Such extended lasting qualities are not necessary with most agricultural equipment. A specific installation may have less than 15,000 cycles in a 10-year period and be used as much as four times daily. Thus, a well made cylinder in a similar installation would become obsolete long before it would wear out.

Efficiency of Speed Force Ratios

High-pressure pumps operate at favorable efficiencies which may be as high as 95 per cent. Cylinders also have good efficiencies. Linear motion at any relatively low velocity may be obtained in one step from the pump to the cylinder. This requires the proper diameter of cylinder for a given pump capacity. By similar reasoning, any desired force may be obtained with a given amount of power.

Major power losses occur in the fluid flow between the pump and cylinder. These may be controlled and held within desired limits by use of adequate lines. The relative efficiency of a mechanical and a hydraulic system to provide a high mechanical advantage is much in favor of the hydraulic system.

Specialized and Experimental Use

The design of this cylinder was such as to provide for general application in a variety of uses. Facilities available in

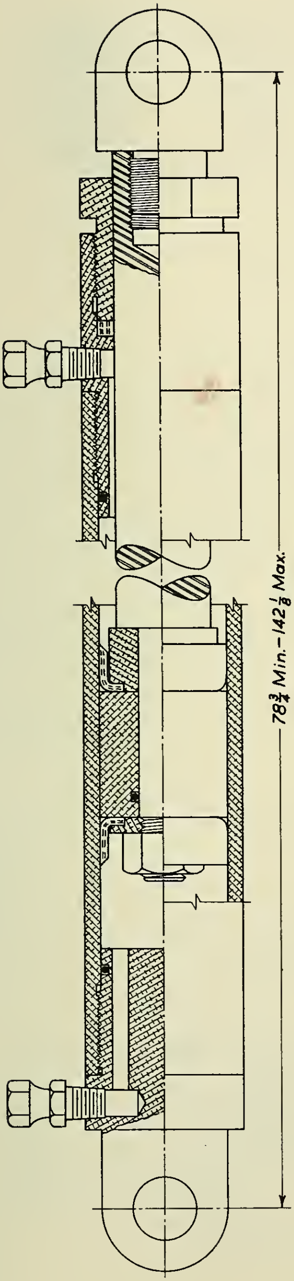

FIGURE 1. Hydraulic Cylinder Assembly.

different shops may require alteration of the design to some extent. Machine work was held to a minimum. Materials used are readily available in most locations and in small quantities. The objectives of (1) light weight, (2) low cost, (3) desired capacity, and (4) reasonable short life were all incorporated into the design. The final result is illustrated in Figure 1. Dimensions can be varied, within structural limits, to any desired size.

Lightweight was accomplished by using aluminum. Extruded tubing and extruded solid stock was supplied by the Aluminum Company of America. The tubing alloy was 6062-T6. The solid stock alloy was 2017-T4. Material cost for this would be high per pound, but reduced machine work would cancel the material cost. The total estimated cost of materials was $40. Each aluminum alloy had a yield point of 40,000 psi. A working stress of 10,000 psi was used for design; however, for the specific application of the cylinder being built, this never became critical.

Cylinder Body

Extruded finishes of the tube were used to reduce machine work. The inside tolerances were within ± .001 as determined with a micrometer. A wall thickness of 0.250 inch was used to provide adequate rigidity. This cylinder wall would withstand a hydraulic working pressure of

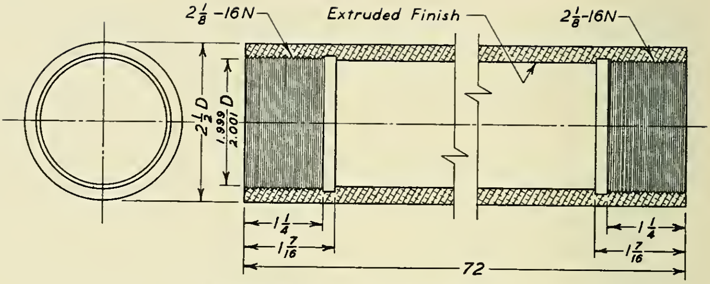

FIGURE 2. Cylinder Body.

2,500 psi, and the threaded ends were designed for this pressure. Threading and facing the ends was the extent of machine work on the body (Figure 2).

Cylinder End

The cylinder end away from the plunger was machined from solid aluminum stock (Figure 3). The "O" ring seal was placed so that no lateral pressure was on the machined part of the cylinder body. Some shops would prefer welded construction at this end, but threaded assembly had the advantage of providing for the removal of both ends for inspection of the cylinder body. Close tolerances were required only for the "O" ring groove.

Packing Gland

Solid stock was used for this piece. Tubing with 1.5 inches inside diameter would have been as satisfactory as the solid stock. External threads and the "O" ring groove of this piece were identical with those of the cylinder end. The oil passage along the plunger rod was designed to have a cross section of the same area as available in one-quarter inch pipe fittings. Space was provided for one-quarter by one-quarter inch linear packing around the cylinder rod and clearance for the packing nut to compress this packing in the packing gland (Figure 4).

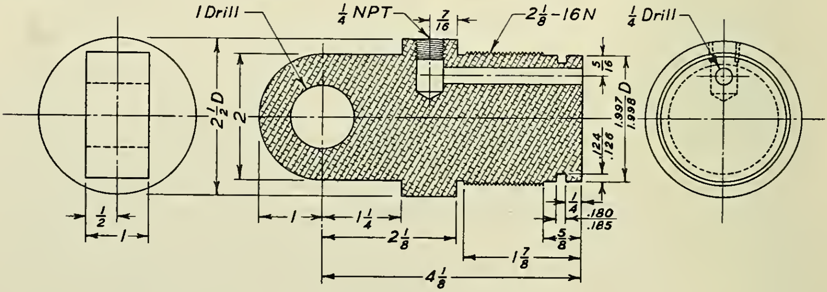

FIGURE 3. Cylinder End.

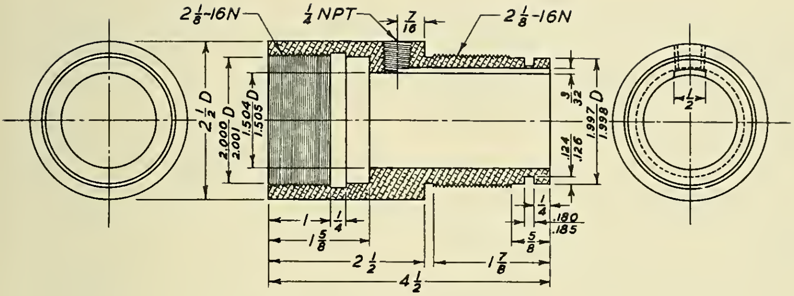

FIGURE 4. Packing Gland.

Packing Nut

Solid stock was again used, although tubing with 1.5 inches inside diameter would have been as satisfactory. Tolerance between the plunger rod and the packing nut was held close so that the nut would act as a wiper to keep foreign matter away from the packing. The close fit also reduced the tendency for the packing to extrude (Figure 5).

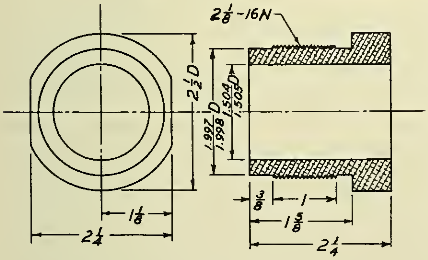

FIGURE 5. Packing Nut.

Plunger Rod

Machine work was held to a minimum by using cold rolled steel and machining only the ends of the rod (Figure 6). A diameter of 1.5 inches provided a favorable l/r ratio of less than 170, assuming the cylinder body to be completely supported. A 1.25-inch diameter would give a ratio of more than 200 when the plunger was extended. American Institute of Steel Construction working stresses allowed a load of 9,150 pounds with the plunger rod fully extended and with no eccentric loading. Since the maximum design load of the cylinder was 7,850 pounds, this would allow for a small eccentric load. Such loading could possibly be caused by friction

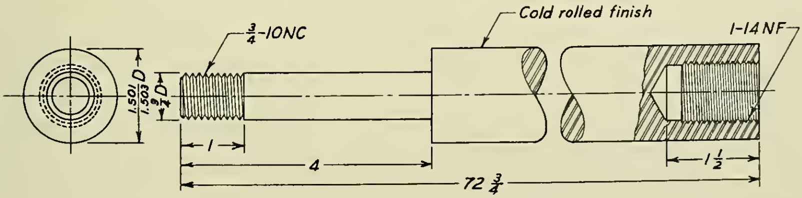

FIGURE 6. Plunger Rod.

in the pins of a flexible linkage, or by tolerances of fabrication. This design load was approximately one-fourth of the ultimate load as calculated by Euler's column formula.

When the cylinder body is not supported and the rod end is considered, the maximum column length increases from 63.5 inches, used for the above calculations, to 142.75 inches. The ultimate load calculated by Euler's column formula, $P = \Omega \pi^2 \frac{EI}{l^2}$ where

P = load
Ω = factor for end conditions = 1 for round ends
E = modulus of elasticity
I = least moment of inertia in inches^4
l = length of column (inches)

would be 3,490 pounds, and independent of the fiber stress of the steel rod. The modulus of elasticity used for steel was 29 million pounds per square inch. An aluminum alloy (Alcoa 2017-T4) with a modulus of elasticity of 10.5 million pounds per square inch was also used for the plunger rod and had an ultimate strength of 1,265 pounds with the cylinder body unsupported. Obviously, these loads present great limitations for the cylinder under these particular conditions. However, for a long column the load increases as the inverse square of the length. As the cylinder contracts, the center of the column moves from near the end of the cylinder body where the plunger rod diameter controls the slenderness ratio, towards the center of the cylinder body. Thus, the ultimate load of the plunger rod would be approximately equal to the design load of the cylinder at an extension of 46 inches. Certain applications could possibly be practical with the cylinder body unsupported if the actual load were always a reasonable amount below the ultimate load for any amount of extension.

Plunger Assembly

The plunger (Figure 7) was made relatively long to conform with standard practice. This helps to give stability when the cylinder is extended. Tolerances for the outside diameter were held close to reduce tendencies for extrusion of the cups. The "O" ring was to seal the high pressure side from the low pressure side, and the location or type of this seal was not critical. The cup hub (Figure 8) on the

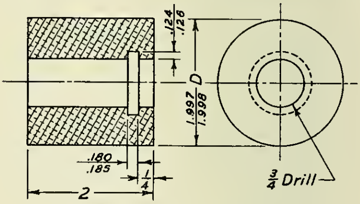

FIGURE 7. Plunger.

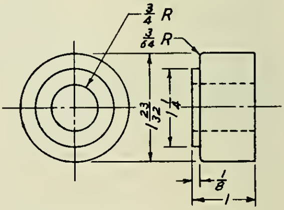

FIGURE 8. Cup Hub.

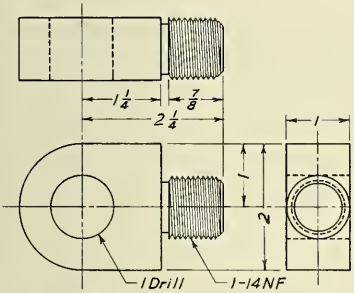

FIGURE 9. Plunger Rod End.

extension side of the plunger acted as a stop at full extension of the cylinder and gave protection to the cup. The plunger rod supplied adequate protection for the other cup if the cylinder was contracted without the rod end (Figure 9) which normally acted as a stop. The hubs (Figures 8 and 10) were sized to hold the cups firmly without excessive force and to allow for slight lateral flexibility. Leather water pump cups were used as they were readily available and the assumption was made that leather would produce as much erosion on the cylinder wall for test purposes as any cup material. After some use, a cup expander was added to the cup on the nut side of the plunger. The assembly was held together by a standard three-quarter inch course thread hex nut.

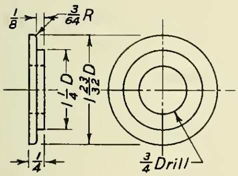

FIGURE 10. Cup Hub.

Cylinder Performance

The cylinder was mounted on the experimental hay drier for which it was designed (Figure 11). An automatic reversing valve, which is shown on the cylinder, kept the plunger cycling as long as fluid was supplied. A counter was connected to the reversing mechanism to obtain the number of cycles the cylinder made. The pressure relief valve was never set above 1,000 psi since this gave the maximum force desired on the hay drier.

The cylinder was supported by the connecting pins as a short cylinder would normally be supported. When the plunger was extended, the 1,000 psi gave a force (3,140 pounds) near the ultimate and the cylinder would deflect considerably when eccentricity was applied by a lateral hand push on the cylinder. No failure was encountered. Supports in a later model of the drier consisted of the pin at one end of the cylinder and a clamp to hold the rod end of the cylinder in place. The pushing plate was equipped with loose fitting guides. This gave considerably more safety from any side thrust that would accidentally be applied to the cylinder.

An aluminum rod was tried with this mounting, but excessive deflection occurred before the desired loads were reached. This deflection was at loads below those calculated for long column action, which indicated that eccentricity was introduced by the pin connections. Controls were manually operated and guides afforded enough support that loads were removed before exceeding the elastic limit of the plunger rod.

Expansion of the cylinder due to pressure was calculated to be one-thousandth of an inch at 5,000 psi. No measurement of change was obtained up to the 1,000 psi at which the cylinder was operated. Thermal expansion for aluminum is twice that of steel or an increase of one-thousandth of an inch on the cylinder diameter for approximately every 40 ° F temperature rise. The average temperature rise encountered with one horsepower input was slightly less than 30 ° F and the micrometer measurements indicated one-thousandth inch expansion. Most packing materials would accommodate this thermal change of dimensions as the aluminum plunger would expand at approximately the same rate as the cylinder.

Total operation of the cylinder has been an estimated 20,000 cycles with varying pressures up to 1,000 psi. The counter was used only for some 300 cycles because the cylinder was required to operate through a definite stroke to actuate the counter. This hampered the practical use of the cylinder control valve. After one year's operation and approximately 2,000 cycles, the plunger cup used for extension was deformed so the lip of the cup did not seal on the cylinder wall. This was corrected with a cup expander. Measurements

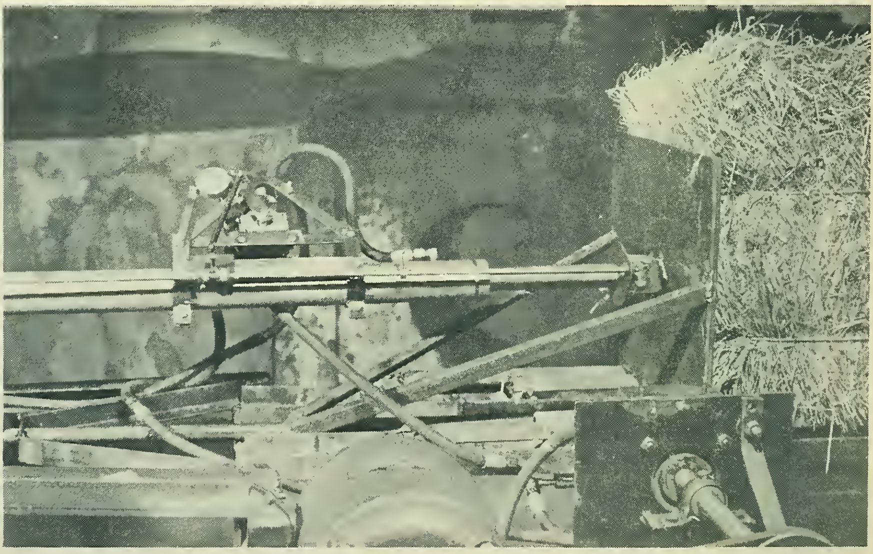

FIGURE 11. Hydraulic System for Pushing Hay Bales into an Experimental Drier.

were made periodically with a micrometer on the inside diameter of the cylinder and on the diameter of the cold rolled steel plunger rod. Neither diameter changed enough in the estimated 20,000 cycles to indicate a change of dimensions. The wear was less than five ten-thousandths of an inch. After a few cycles (less than 100) of operation, wear marks were clearly visible on both the plunger rod and on the inside of the cylinder indicating a seating of the plunger cups and the plunger rod packing.

The packing nut required frequent adjustment to prevent oil leakage around the plunger rod. The first adjustment after reassembly was required between 50 and 100 cycles and subsequent adjustments at approximately 500-cycle intervals. A graphite-filled asbestos packing was used. Other types might require much less attention. The maintenance presented no difficulty in the research operations. Replacement of either packing or cups did not appear necessary before at least 100,000 cycles of operation.

One precaution was used in storing the cylinder. The cylinder was contracted to prevent corrosion of the cylinder rod. The adhering oil would not give adequate protection and rusting occurred after an exposed period of one month in an unheated building. The length of permissible exposure would vary considerably with weather conditions.

Summary

The aluminum hydraulic cylinder with a cold rolled steel plunger rod was satisfactory for the application for which it was designed. The extruded finish of the tubing and the cold rolled surface of the steel gave adequate performance with the plunger cups and packing used.

Factors which should be observed in the design of similar cylinders are (1) the low modulus of elasticity of aluminum where column action becomes critical, and (2) the high thermal coefficient of expansion where excessive temperature changes are involved and a close fit is required with steel. Seals must accommodate the dimensional changes of either pressure or temperature.