Design of the Hydraulic Rotary Cylinder And Drawtube

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Abstract : This paper presents the design and manufacturing of hydraulic rotary cylinder and a drawtube. There is no cheaper and reliable method except for this, which can be used for clamping or releasing pipes, drill bits or other operative tools. This paper gives us the brief about the design and construction of Hydraulic Rotary Cylinder which can be used for various purposes. Using this innovative method we were able to achieve clamping of pipe of 6.25mm in diameter and 6m in length. This proved very effective as the cost of using an electric operated rotary table for the same purpose would be almost thrice the value of using hydraulic rotary cylinder with drawtube. This an whole setup is very robust and maintenance free for years.

***Index Terms* – Stiffness; Torque; Constraints; Duty Cycle, Collet.**

I. INTRODUCTION

Hydraulic rotary Cylinder also referred as a rotary manifold, swivel joint, rotating joint, rotary coupling, fluid swivel or fluid rotary union (FRU). The simplest actuator is purely mechanical, where linear motion in one direction gives rise to rotation. Some machine actions require rotary motion for only a portion of a turn. Using a hydraulic motor to perform a partial-turn function is expensive and it is difficult to accurately stop a motor at a specified degree of rotation. Hydraulic rotary cylinders can be used for high torque, heavy-duty motion applications. They have high load capacities, high power-per-unit weight and volume, good mechanical stiffness, and high dynamic response. They provide the heft for lifting, turning, indexing, clamping, mixing, bending, testing, and steering applications among others. Rotary actuators are compact and efficient, and produce high instantaneous torque in either direction. This makes them widely used in precision control systems and in heavy-duty machine tool, mobile, marine, material handling, conveyors, robotics and aerospace applications. Rotary motor actuators are coupled directly to a rotating load and provide good control for acceleration, operating speed, deceleration, smooth reversals, and positioning. They allow flexibility in design and eliminate much of the bulk and weight of mechanical and electrical power transmissions. Because they are fully enclosed, they withstand harsh conditions and are protected from dust, dirt, and moisture.

II. OBJECTIVES

a) Cost Reduction – This is the most important aspect for choosing hydraulic rotary cylinder over its alternates. If employed properly it can reduce costs by a huge amount.
b) Robustness – Hydraulic equipment in general are very robust and have a good working life. This is no different it can operate for years without much need of maintenance.
c) Simplicity in Design and maintenance – These are usually very simple in design and require only few components to manufacture
d) Offer Flexibility – These offer great range of flexibility, they can be adjusted to carry a wide range of loads. Simply by adjusting the pressure valves.
e) Modifiability – As these are flexible, they can be modified as well, with minor replacement of parts.
f) Promote Safety in a facility – Other alternates may prove to be dangerous in extreme working conditions ie heating, breaking down. But hydraulics rotary cylinder is capable of working even under harsh conditions.

III. METHODOLOGY

Major components which are required to manufacture Hydraulic Rotary Cylinder include seals, bearings, shaft, retaining ring, and housing. Further there are fluid passages that allow liquids (oils) to transfer simultaneously without compromising with loss in pressure.

Design of the hydraulic rotary cylinder depends on the application requirement. These generally include,

a) Pressure.
b) Speed.
c) Temperature of operation.
d) Fluid Type.
e) Fluid Passage Size.

f) Number of Fluid Passages.
g) Applied Loads.
h) Design Constraints.
i) Economic Constraints.

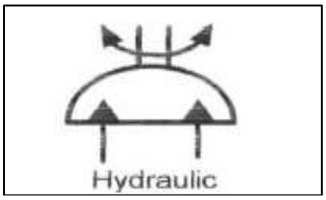

Fig-1: Symbol for Hydraulic Rotary Cylinder

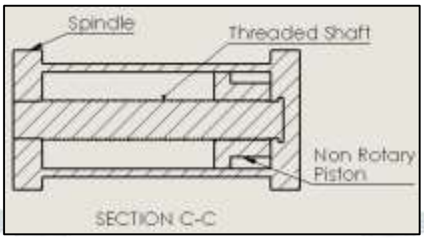

Fig-2: Section View 1

Calculating Torque Necessities:

Design torque represents the maximum torque that an actuator is required to supply in an application. The Design Torque is always taken higher than total required load. Therefore, the design torque is given by,
$M = M_t \times FOS$

$M_t = (M_l + M_f + M_a)$

Where, M_t is total torque
$M_{l:}$ Load Torque
$M_{f:}$ Friction Torque
M_a: Acceleration Torque

Calculating Mass Moment of inertia:

$I = K \times m \times R^2$

Where, K: inertial constant
m: mass of the body
R: distance axis and rotating mass

For example, we calculated torque for threaded shaft fitted with collet and a force requirement of 2.5kN.

$M = F_p/2\pi$

$M = (2.5 \times 101.97)/ (2\pi)$

M = 40.572 kg-m

Calculating Kinetic Energy
$KE = 0.5\ I\omega^2$

Calculating Cylinder Speed
V = 231Q/ (720A)
Where,
V: velocity or speed of rotor in feet/second

Calculation of the angular velocity
$\omega = \theta /t$ (rad/s^2)
Calculation of the inertial energy of the load

$E = 0.5 \times I \times \omega^2 \times 10^{-1}$ (mj) / 10,000

Calculating Rotary Cylinder Volume Capacity
Volume (gallons of oil) = Net area× Stroke/231

Calculating Required Pump Flow and Flow Rate for the cylinder
Q = V/t
Where,
Q: flow rate
V: Displacement
t: time to fill displacement

Q = 12× 60× velocity × net area / 231
Here, Q is in GPM
For time in seconds,
t = 0.06 × V/Q

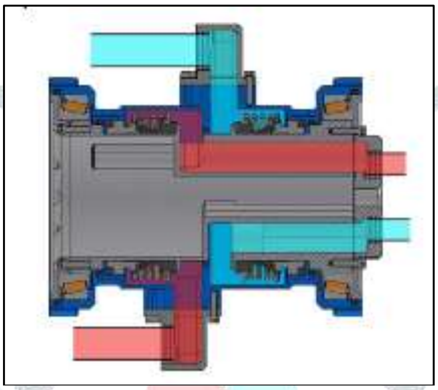

Fig-3: Fluid Flow inside the Cylinder

Fluid Motor Power (HP) = Torque output (inch pounds) × rpm/ 63025

For Pump Outlet Flow
Flow (gallons per min) = rpm × Displacement / 231

Pump Input Power (hp) = (flow rate output× pressure) / (1714× efficiency)

Flow rate through piping
V = PV / 250000 (it is usually 0.5% per 1000psi)

Calculating Fluid Motor Torque
Torque = pressure × displacement/2π

Calculating Fluid Motor Speed
n = 231Q/d
Where,
n: motor speed

Minimum Time for the Flow must be
$T \geq (2I\theta^2/E)^{1/2}$

Designing Rotary Cylinder Seals
There is a wide range of different, price, wear and friction. Usually the pressure velocity rating, i.e. a value equivalent to seal solutions for rotary applications and the choice between them is most likely determined by demands of space, allowable leakage, reliability the work condition in terms of rotational speed and pressure as seen in Equation (1), is calculated and used to dimension and select a suitable seal solution.
$(PV) = P_f \times V$
Where,
P_f: face load (MPa)
V: peripheral velocity

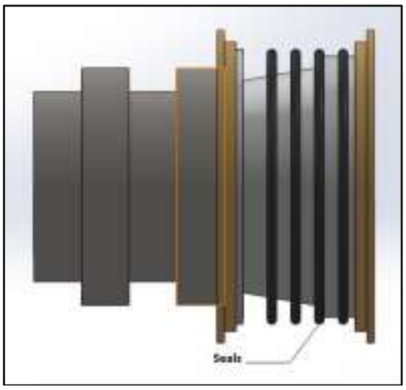

Fig-4: Seals

Calculating Life of Bearings
$L_{10}= (C/P)^p$
Where,
L_{10}: nominal life in terms of million revolutions

Flow can be determined (inside the cylinder) by using Reynolds Number i.e. Ratio of momentum forces to viscous forces
Re = wd/ν

Determining Rotary Actuator Size
In a rotary actuator the force is produced by applying pressure to the piston and the distance is produced by the rack and pinion gears. Duty cycle, torque and pressure are the determining factors when sizing a rotary actuator. The rotary actuator must be able to exceed the duty cycle, deliver sufficient torque to move the load and also to withstand the pressure required to stop it. It should be noted that the back pressure, generated during cushioning, is often greater than system pressure. A method for determining the smallest rotary actuator, for a given application, is described below.

a) Determine the duty cycle of the actuator.
b) Determine maximum allowable safe system pressure that all the system components can withstand.
c) Calculate the design torque from the equation;
   $M = M_t \times FOS$
d) Taking into account the duty cycle pressure and torque requirement of the application, select an actuator that is larger than your requirements.
e) Calculate the system operating pressure based on the Demand Torque and the torque/pressure data for the selected actuator– less than the maximum safe system pressure.
f) Check the flow rate required by the rotary actuator. Adjust the flow rate (if required), by either reducing the rotational mass moment of inertia of the load or using a relief valve
g) Adjust the fluid velocity to reduce cavitation and turbulence in the fittings.
h) Monitor for unexpected shocks and loading on the system, this can lead to failure of the system.

Hydraulic Rotary Cylinder is preferable when mounted on the strong base (if available) or else it is preferable to create a flange of appropriate thickness. The thickness of the flange may vary with constraints and application. Improper selection of flange can be lead to failure, as very thin flange will be crushed and a thicker flange will increase weight of the system.
Number of Screw/bolts for flange can be determined by
$N = (4P_0 \times A_{channel})/ (0.7\times \sigma_{yield} \times\pi\times d_{screw}{}^2)$

Design of Bearings
Rotary Cylinders are generally used for heavy loads such as that of an excavator, marine equipment etc. Therefore, these exert a very high load on bearings. Which help the assembly to absorb the load. Also, bearings ensure smooth working of the rotary cylinder.
For Ball Bearings,
Equivalent Dynamic Bearing Load (Angular Contact Ball Bearing)
$P = F_r + 0.55F_a$ when $F_a / F_r \leq 1.14$
$P = 0.57F_r + 0.93F_a$ when $F_a/F_r \geq 1.14$
Where,
F_a: Axial load (kN)
F_r: Radial load (kN)

For Roller Bearings
$P = F_r$ when $F_a / F_r \leq e$

$P = 0.4F_r + YF_a$ when $F_a / F_r \geq e$

Where, e: calculating factor

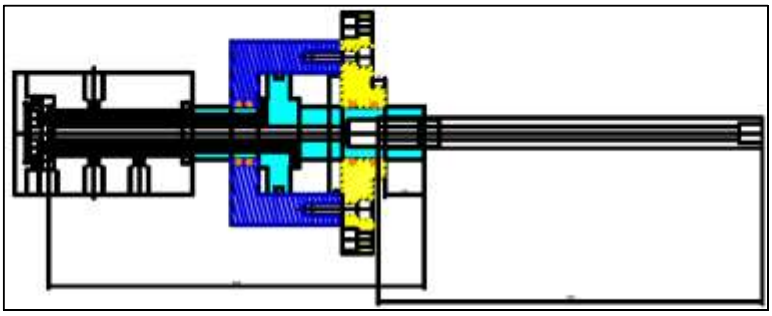

Fig-5: Assembly of Hydraulic Rotary Cylinder and Drawtube

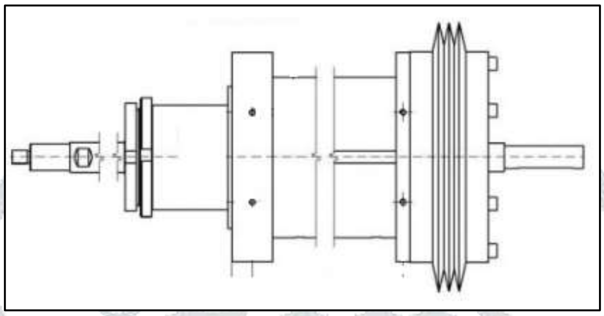

Fig-6: Rotary cylinder, drawtube and collet assembly

Hydraulic Circuit for rotary Cylinder

A hydraulic circuit is a group of components such as pumps, actuators, control valves, conductors and fittings arranged to perform useful work. There are three important considerations in designing a hydraulic circuit: 1. Safety of machine and personnel in the event of power failures. 2. Performance of given operation with minimum losses. 3. Cost of the component used in the circuit. When designing hydraulic operating circuits for rotary actuators, consideration should be given to the following criteria:

– Actuator rotational velocity
– Kinetic energy developed
– Actuator holding requirements
– System filtration

The composite drawing below shows general recommendations for sample circuitry, and is intended as a guide only. Flow control valves (1) in the meter-out position provide controlled actuator velocity. Care should be taken if the load is to move over centre, as the combination of load and pump generated pressure may exceed the actuator rating. To protect the actuator and other system components from shock pressures caused when the actuator is suddenly stopped in mid-stroke, cross-over relief valves (2) should be installed, as close to the actuator as possible. These relief valves also protect the actuator and system if the load increases and 'back-drives' the hydraulic system. A sample hydraulic circuit is given,

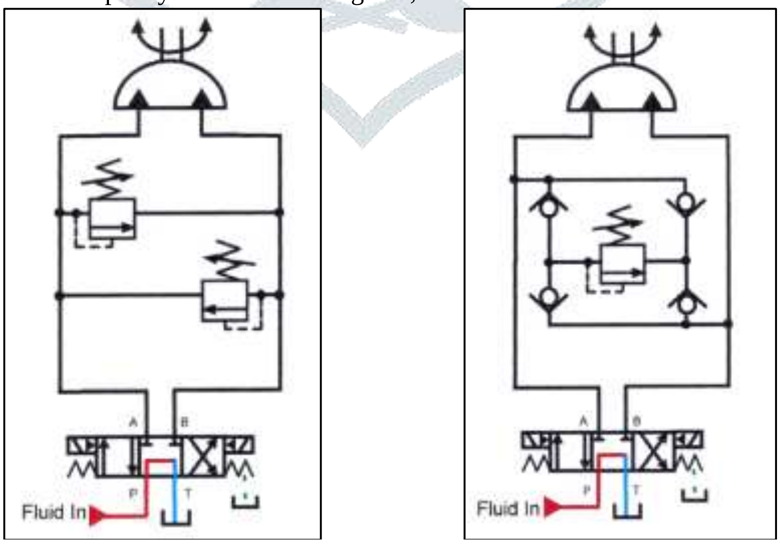

Fig-7: Sample Hydraulic Circuits For Hydraulic rotary Cylinder.

Design of the Drawtube

.Drawtube is long and thick hollow tube with threads at both the ends. One end of the drawtube is connected to rotary cylinder while the other is fixed to a tool or a jig (like collets). Drawtube serve three basic functions in mechanical systems; 1) to provide a clamping force 2) to restrict or control motion, and 3) to transmit power. Geometrically, thread is a helical incline plane. A helix is the curve defined by moving a point with uniform angular and linear velocity around an axis. These are usually made from mild steel, stainless steel etc. The design of drawtube depends solely on constraints, like space available, force and torque required and availability of material.

Manufacturing of drawtube may become complicated; the threads at both the ends should match each other. This requires precision machining either on lathe or on CNC. After completing machining the drawtube is coated with anti-rust coating to prevent corrosion even in harsh conditions. Threads on the drawtube can be determined by, the thread tensile stress area, which can be discovered with this equation. The stress is correlated to the TPI of the bolt.

As= π/4 X (D - (.938194 X p)) ^2

Where: As: tensile stress area

D: bolt diameter

p: 1/threads per inch (TPI)

Threads on both metric and UTS fasteners are also categorized as coarse, fine or extra-fine. UTS thread types are typically labeled UNC (Unified Coarse), UNF (Unified Fine) or (Unified Extra Fine (UNEF). There is no difference in manufacturing quality between coarse, fine and extra-fine thread types, but there are differences in how they are employed. We usually prefer fine threads, their smaller pitches and greater TPI equate to better tensile strength, and a larger minor diameter provides better shear strength. Smaller thread helix angles also provide superior resistance to vibration in fine-threaded fasteners, a very important consideration. Thin materials are appropriate for fine and extra-fine threads. These are also more useful for precision applications.

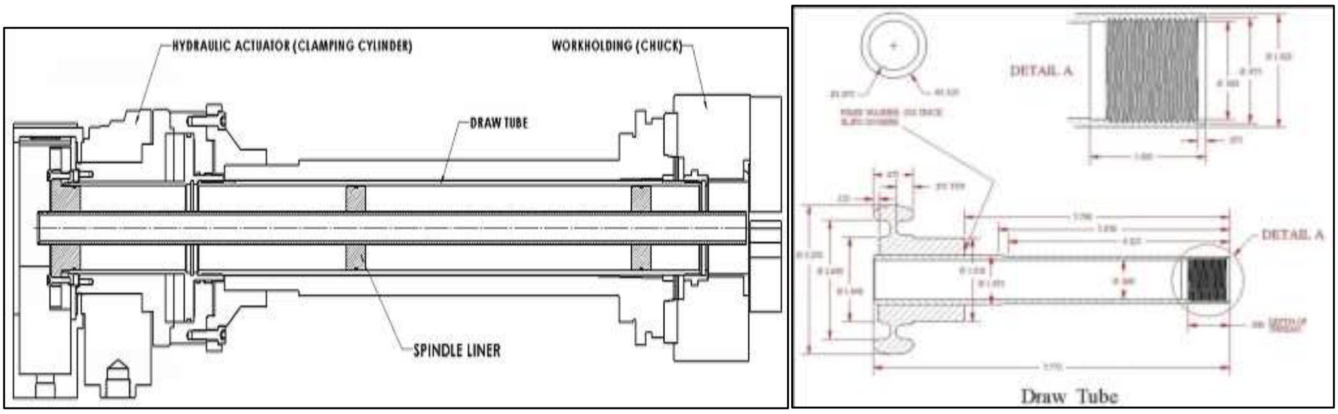

Fig-8: Connected Drawtube

Analysis of a Drawtube

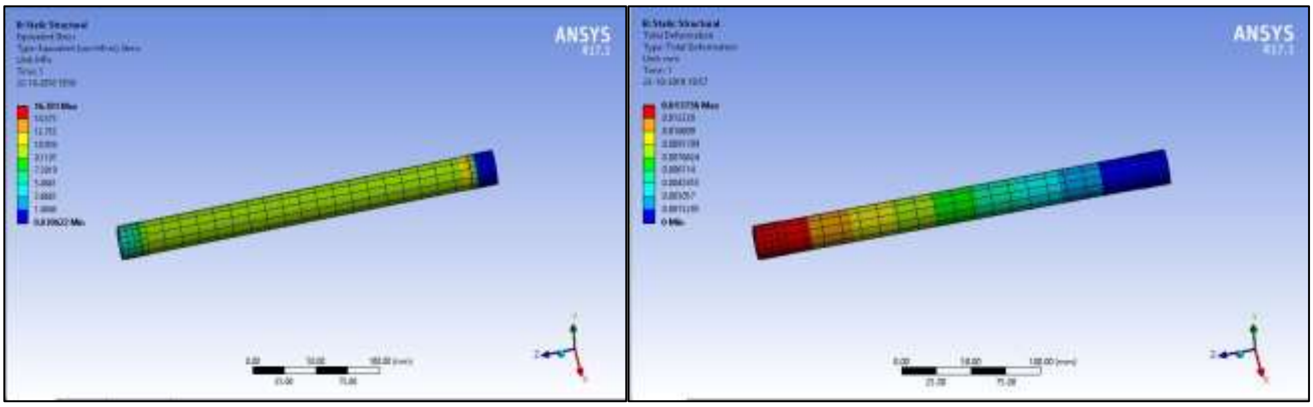

Fig-9: Analysis using Ansys

Here, a drawtube was manufactured by us at a facility. Before manufacturing it, was analyzed using Ansys. We made a drawtube with length of 287mm, 25mm outer diameter, 18mm inner diameter and 20mm threading on both the ends. We tested it by applying force of 2.5kN.

IV. CONCLUSION

The design of the hydraulic rotary cylinder was found to be realistic and feasible when tested on a ANSYS software. As per our objectives, the rotary cylinder and drawtube was manufactured using this method and was found to work smoothly as per requirement and with no signs of failure. This also is employed in a machine. This method helped in cost reduction by almost by half the amount without compromising the working effectiveness requirements. The simplicity in design reduces complexities. Further, the robust components require almost no maintenance.

V. ACKNOWLEDGEMENT

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