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The linkage between fluid power and mechanics

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ABSTRACT: Fluid power and mechanics are traditionally taught as separate courses in engineering and engineering technology curricula. It is suggested in this article that it would be beneficial for students to solve problems in their coursework that require the use of knowledge from both fields. It would help students to realise that these courses are interrelated and make them solve more realistic problems that they could encounter in their future careers. Careful mechanical analysis can also extend the life of actuators and machines. Two example problems illustrate the need for knowledge of fluid power and mechanics. One of the example problems requires knowledge of statics and fluid power, whereas the other problem requires a knowledge of statics, strength of materials using stress analysis and fluid power. These problems are illustrative of the type of problems that engineers may run into while on the job. Many other practical problems could have been included, such as those dealing with hydraulic forming presses, the torsion of a hydraulic motor shaft, cylinder rod buckling, the sizing of a pneumatic motor used to winch up a load using pulleys, etc.

INTRODUCTION

Fluid power is the study of power transmission using hydraulics or pneumatics. The expression *fluid power* may be used to describe any process, device or system that converts, transmits, distributes or controls power through the use of pressurised liquid or gas [1].

The main fluids used in hydraulics are usually petroleum-based oils, but synthetic and water based fluids are also used in some cases for safety reasons. Compressed air is usually the medium of power transmission in pneumatics. Fluid power is an old technology that began to develop rapidly at the beginning of the 20th Century.

According to Esposito, the advantages of fluid power are as follows:

- Ease and accuracy of control;
- Multiplication of force;
- Constant force or torque;
- Simplicity, safety and economy [2].

Today, fluid power has grown into a sophisticated technology controlled by electronics and microprocessors. It has grown into an US$8 billion dollar industry that employs some 340,000 people in the USA alone, according to the National Fluid Power Association [3].

Mechanics can be defined as that branch of the physical sciences that is concerned with the state of rest or motion of bodies that are subjected to the action of forces [4]. The branches of mechanics are statics, dynamics and mechanics of materials. Statics deals with the equilibrium of bodies, that is, it is used to determine the forces, acting either external to the body or within it, which are necessary in order to keep the body at rest or moving with a constant velocity. Dynamics is the study of bodies having acceleration due to unbalanced forces. Mechanics of materials studies the relationships between the external loads and the intensity of internal forces acting within the body. It also looks at stresses and strains within bodies.

Mechanics courses are taught in most engineering and engineering technology curricula. Fluid power is taught in some engineering and engineering technology curricula. These courses are usually taught as two separate courses. The authors believe that there is an overlap in these subjects and that problems resembling those encountered in daily activity should be assigned to students who take these courses, as it would help reinforce the material taught in both subjects.

It is suggested that introductory fluid power classes be taken first for those programmes where both fluid power and mechanics are included. This is suggested because one of these subject areas has to come first if their interrelationships are to be considered. This should then be followed by mechanics classes, such as statics, strength of materials (mechanics of solids) and possibly dynamics. It is suggested that in these classes, several problems should be assigned that are related to fluid power so that the student will obtain a more realistic viewpoint of both fields. A further benefit of a careful mechanical analysis would be the extension of the life of actuators. The life of actuators can be extended by careful considerations made during the design of actuators, during the design stage of the machine, during installation and start-up, with regard to operation and maintenance.

The three types of failure in fluid power systems are:

- Degradation of components over time;
- Intermittent failure;
- Catastrophic failure [5].

It is known throughout the fluid power industry that most failures are caused by fluid contamination. A generally accepted statistic states that approximately 75% of fluid power component failures are caused by contamination, but the other 25% is fairly evenly distributed between catastrophic failure and obsolescence [6]. Careful mechanical analysis can reduce the latter percentage.

TWO PROBLEMS TO IMPROVE UNDERSTANDING

In this article, two example problems will be discussed that will help fluid power designers understand that most mechanical designs have to first undergo a mechanics of materials analysis and that analysis by trial and error is too time-consuming and costly. On the other hand, engineers with a mechanics background will appreciate the fact that the results of their extensive calculations have to be further analysed to size hydraulic or pneumatic systems.

There are problems that can be found in several fluid power texts that require a limited knowledge of mechanics of materials, but it is usually treated as a side subject with little detail and not emphasised so as to use the knowledge gained in both fields. The authors have not encountered any mechanics texts requiring further knowledge of fluid power component sizing after a detailed mechanical analysis.

One of the goals of this article is to point out to educators in programmes where both fluid power and mechanics are important that problems can be assigned that will require their students to use knowledge from both fields. The linkage of problems from both fields will help students to more fully appreciate both subjects and give them more realistic applications for future use in their engineering careers.

The remainder of the article presents two sample problems where knowledge of both fluid power and mechanics is required to design the final system. Many other problems could have been used to illustrate this linkage between fluid power and mechanics.

EXAMPLE 1

Sample Problem Illustrating the Use of Statics and Fluid Power

The following problem comes out of a mechanics text and has been adapted and changed so that it now also involves the use of fluid power formulae [7].

Given: Determine the force that must be developed in the hydraulic cylinder AB of the shearing machine of Figure 1 in order to develop a normal force of 40 kN in the grip. The jaws are pin-connected at C. Also determine the magnitude of the force components developed in the pin at C. The relief valve setting is 17.24 MPa and cannot be set higher because of the pressure rating of other components in the system. What bore size cylinder should be used for cylinder AB?

Answer: Figure 2 shows the cylinder offset *d*

$d = \sqrt{[(0.1)^2 + (1.2)^2]} = 1.204$ m.

In applying statics to Figure 3 and using the following equations:

$\Sigma F_x = 0$, $\Sigma F_y = 0$ and $+ \circlearrowleft \Sigma M_C = 0$, we obtain $F_{AB} = 86$ kN, $C_y = 85.7$ kN and $C_x = 47.14$ kN.

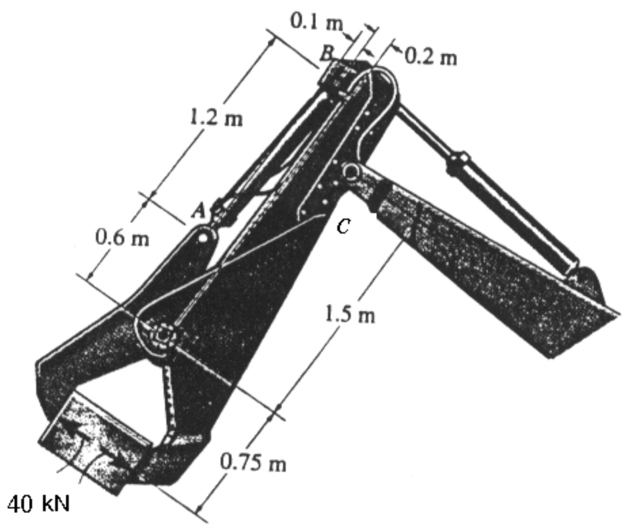

Figure 1: Clamping problem.

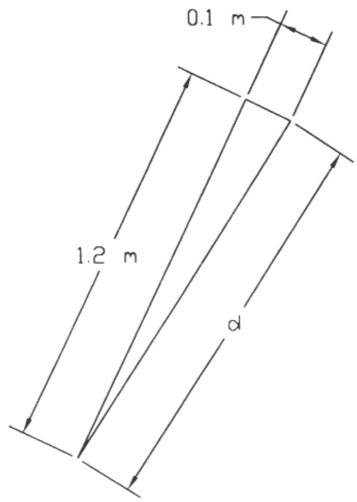

Figure 2: Cylinder offset.

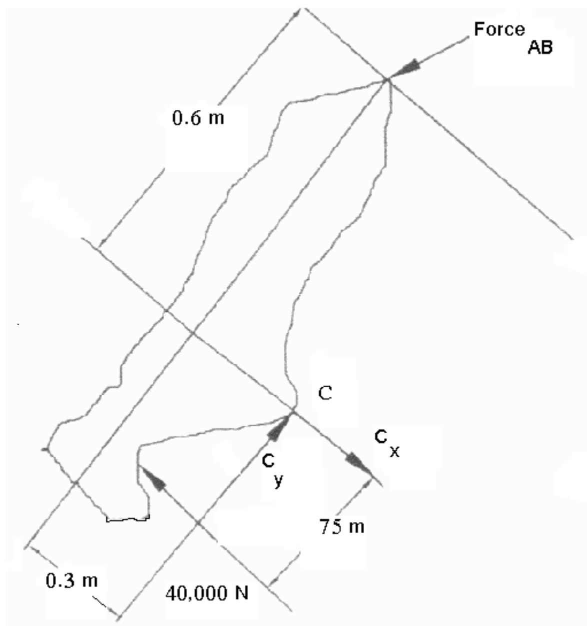

Figure 3: Free body diagram of the bracket.

1. $\sum F_x = 0$: $-Cx + 40 + (0.1/1.204) \times F_{AB} = 0$
2. $\sum F_y = 0$: $Cy - (1.2/1.204) \times F_{AB} = 0$
3. $+ \circlearrowright \sum M_C = 0 : (40)(0.75) - (0.1/1.204 x F_{AB}) \times 0.6 - (1.2/1.204) \times F_{AB} x 0.3 = 0$.

Now we can use the fluid power formula: F = P x A. In this formula, *F* is force in N, *P* is pressure in Pa and *A* is the area in m^2. A = F / P = 86 kN / 17.24 MPa = 49.88×10^{-4} m^2. $\Rightarrow$ $¼.\pi.D^2 = 49.88 \times 10^{-4}$ $m^2 \Rightarrow D = 7.969 \times 10^{-2}$ m. So an 8 cm bore cylinder, at least, should be used. It might be even better to use a 9 cm bore cylinder because it is always good to oversize a little bit.

EXAMPLE 2

Sample Problem illustrating the use of Mechanics of Materials and Fluid Power.

Given: A punch die is used to shear an aluminium alloy (6061-T6) specimen as can be seen in Figure 4 [8]. The ultimate shear stress of the alloy is τ = 165.48 MPa [9]. It is desired for the punch stroke to be 10.16 cm/sec. The retraction stroke has to be 15.24 cm/sec. The relief valve setting of the system cannot exceed 13.79 MPa due to the pressure rating of the other components. The maximum velocity of the fluid in the hose on the blind end side cannot exceed 457.2 cm/sec and on the rod end side, it cannot exceed 609.6 cm/sec in order to prevent turbulence. The work to be sheared is 0.635 cm thick and the width is 10.16 cm. A rod of 7.62 cm will be used for the cylinder.

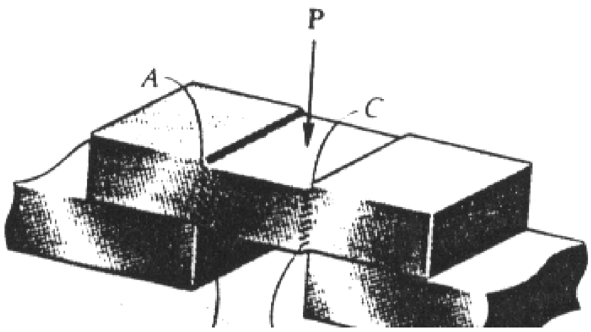

Figure 4: Shearing operation.

Questions:

a. What is the force required to punch through the material?
b. What size bore is needed?
c. What size pump is needed so the punch press can meet the speed requirements?
d. What size hose is needed on the blind end side of the cylinder?
e. What size hose is needed on the rod end side of the cylinder?
f. How many kW of power is used by the system when the punch is shearing through the stock?
g. What size electric motor is needed if the system is 75% efficient?

Answers:

a. The material is in double shear. Apply statics to Figure 5.

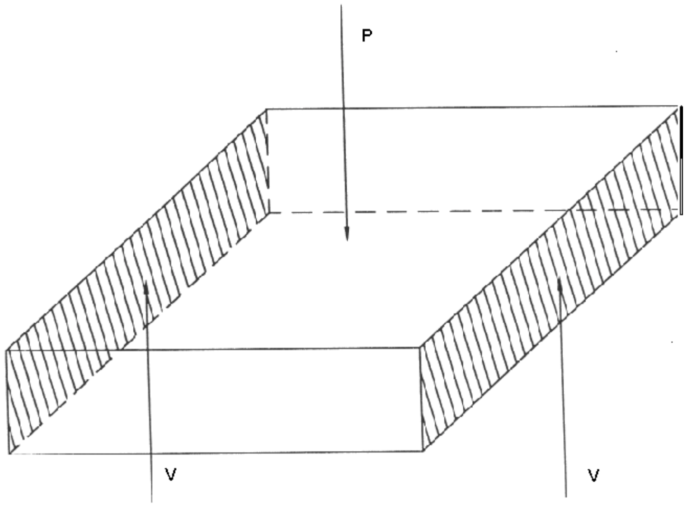

Figure 5: Free body diagram of the sheared piece.

$+ \uparrow \sum F = 0 \Rightarrow - P + 2 .V = 0 \Rightarrow V = P/2$. *V* in this case is the shear force in lbs. The mechanics of the materials equation can now be used: $\tau_{avg} = V/A \Rightarrow V_{shear} = \tau_{avg} . A_{shear}$
In this equation τ_{avg} stands for average shear stress in ksi.
$A_{shear} = (0.635 \times 10^{-2}) \times (10.16 \times 10^{-2}) = 6.45 \times 10^{-4}$ m^2.
$V_{shear} = (6.45 \times 10^{-4}) \times (165.48 \times 10^6) = 106.7$ kN.
P = 2V = 213.46 kN.

b. F=P.A $\Rightarrow$ A=F/P=(213.46x103)/(13.79x106)=154.8x10-4 m2.
A = ¼ . π. D2 = 154.8 x 10-4 m2 $\Rightarrow$ D =14 x 10-2 m = 14 cm.

c. Arod = ¼.π.(7.62)2 = 45.58 cm2 = 45.58 x 10-4 m2 and $A_{blind\ end\ side} = 154.8 \times 10^{-4}$ m^2. $\Rightarrow A_{effective} = 109.22 \times 10^{-4}$ m^2. The extension speed of the cylinder: $V_{extension}$ = 10.16 cm/sec
= 10.16×10^{-2} m/sec. We can now use the fluid power formula: V = Q / A. In this formula *V* is cylinder velocity with the unit of m /min and "A" is area in m^2. Q is flow rate in m^3/sec.
$\Rightarrow Q = V . A = (10.16 \times 10^{-2}) \times (154.8 \times 10^{-4})$
= $1,572.76 \times 10^{-6}$ m^3/sec = 94.36 LPM. (Note 1 m^3 = 1000 L).
V retraction = 15.24 cm/sec = 15.24×10^{-2} m/sec.
$Q = (15.24 \times 10^{-2}) \times (109.22 \times 10^{-4}) = 1,664.51 \times 10^{-6}$ m^3/sec
= 99.987 LPM. So, use a 100 LPM pump for this application since we always size for the largest flow rate.

d. d. Q = V.A. In this formula, *Q* is flow rate in m3/sec, *A* is internal area of the conductor in m^2 and *V* is the velocity of the fluid using the unit m/sec.
$Q=(15.24x10^{-2} m/sec) \times (154.8x10^{-4} m^2) \times (1000L/m^3) \times 60 sec/min. = 2,359.15 \times 10^{-6}$ m^3/sec = 141.55 LPM. We will have to size the blind end side hose on this Q of $2,359.15 \times 10^{-6}$ m^3/sec. The maximum velocity of the fluid in the hose on the blind end side is 457.2 cm/sec. = 457.2 x 10^{-2} m/sec.
$A=Q/V = 2,359.15x10^{-6}$ $m^3/sec/457.2x10^{-2} m/sec = 5.16x10^{-4}$ m^2. $\Rightarrow$ ¼ . π . $D^2 = 5.16 \times 10^{-4}$ m^2. $\Rightarrow D_{hose} = 2.56 \times 10^{-2}$ m = 2.56 cm.

e. The maximum flow on the rod side is 1,664.51x10-6 m3/sec = 99.987 LPM. The maximum velocity of the fluid in the hose on the rod end side is 609.6 cm/sec.

$A = Q / V = (1{,}664.51 \times 10^{-6})/(609.6 \times 10^{-2}) = 2.7305 \times 10^{-4}$ m^2. $\Rightarrow$ ¼ $.\pi.D^2 = 2.7305 \times 10^{-4}$ m^2. $\Rightarrow$ $D = 1.86 \times 10^{-2}$ m = 1.86 cm. We would use the next larger size standard hose.

f. Hydraulic Power = (Q x Psi) / 60,000. In this formula, hydraulic power is in kW, flow rate is in LPM and pressure in kPa. Hydraulic Power = (13,790 x 94.36)/60,000 = 21.69 kW.

g. Power electric motor = 21.69 kW /0.75 = 28.92 kW.

CONCLUSION

Fluid power and mechanics are intertwined and should be taught to students in a way that shows the relationship between them, rather than as separate courses. Students would obtain a more a realistic education by solving real world problems utilising knowledge from both fields. This would also help improve the design of machines and extend the life of actuators and machines.

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