Piston Actuated Linkages

Introduction:

There are two main considerations when designing mechanisms with pistons.

Range of Motion:
The range of motion is usually defined by what you are trying to do, i.e. move some load from point A to point B.

Torque:
The torque needed is defined by the desired load and the geometry of the linkages.

Like any other mechanical advantage system (pulleys, levers, wedges, etc.), there is a trade off between torque and range of motion (in this case). Your goal as a designer is to find a balance between the two.

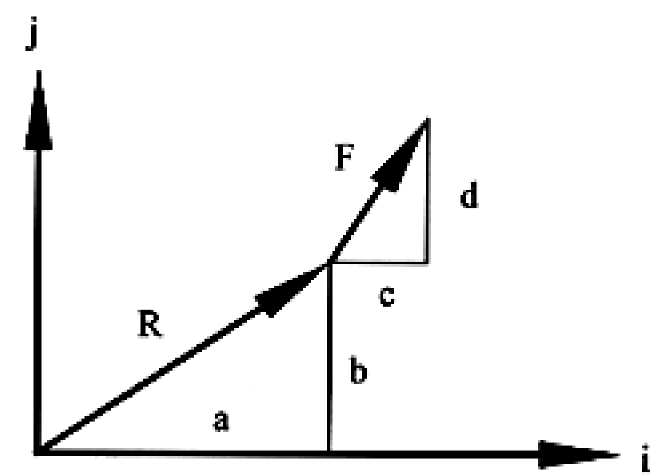
In real life you would define your range of motion requirements. Then derive your torque or force requirements. Once these are known, you would buy an appropriately sized piston. In 2.007 your options are much more limited. On a 2.007 linkage you can use one piston, or both.

Do not forget that the pistons in the kit have more force pushing than pulling.

Torque:

To analyze pistons and arms, or other situations involving torques, it is very useful to break up the system into component vectors, and solve for torques using the cross product of these vectors.

This is much easier to model in a spreadsheet, than keeping track of all the angles involved:
$$Torque = Force \cdot Radius \cdot \sin\theta$$



$$R = ai + bj$$
$$F = ci + dj$$
$$\Gamma = ad - bc$$

Fig 1: A torque (a force F applied at some radius R) about a point (the origin) in component vectors.

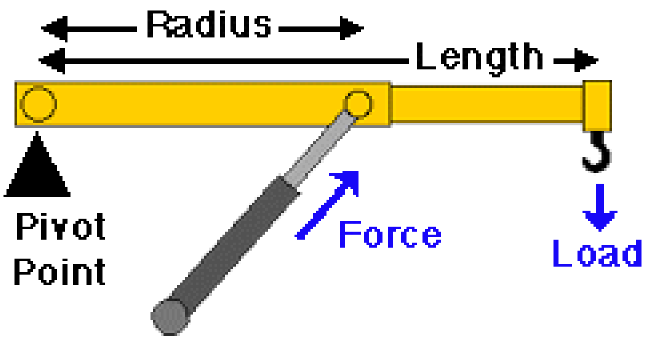


Fig 2: This is a drawing of a basic piston boom assembly. It has all the elements shown in fig. 1, and a second force-radius pair (the Load and Length) has been added. The force needed from the piston is simply solved by setting the moments equal about the pivot point. What happens as the boom is pushed up (away from horizontal)? Does the force required from the piston become greater or less?

Binding and Jamming:

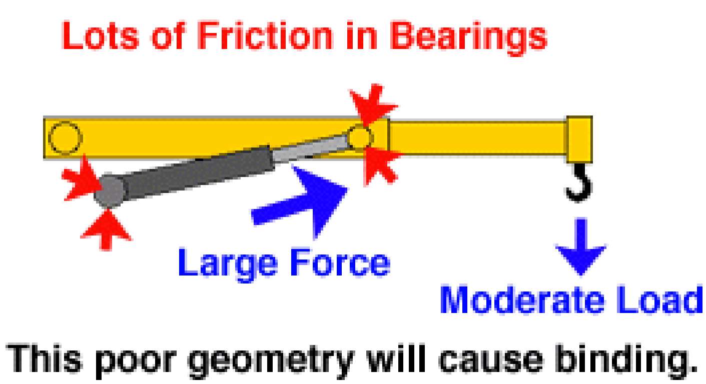
If the geometry is done incorrectly, the piston assembly will bind or jam. Remember, maximum torque is achieved when the force is applied at right angles to the radius. You should design your linkage to take maximum advantage of this.

You should avoid having the angle between the piston and the arm small! This requires a lot more force to achieve the same amount of torque on the geometry. In addition, small angles increase the load on the bearings dramatically, which results not only in even higher force demands to achieve the required torque, but also in an increased wear rate. At evern smaller angles the system will bind or jam.

What is the difference between binding and jamming?

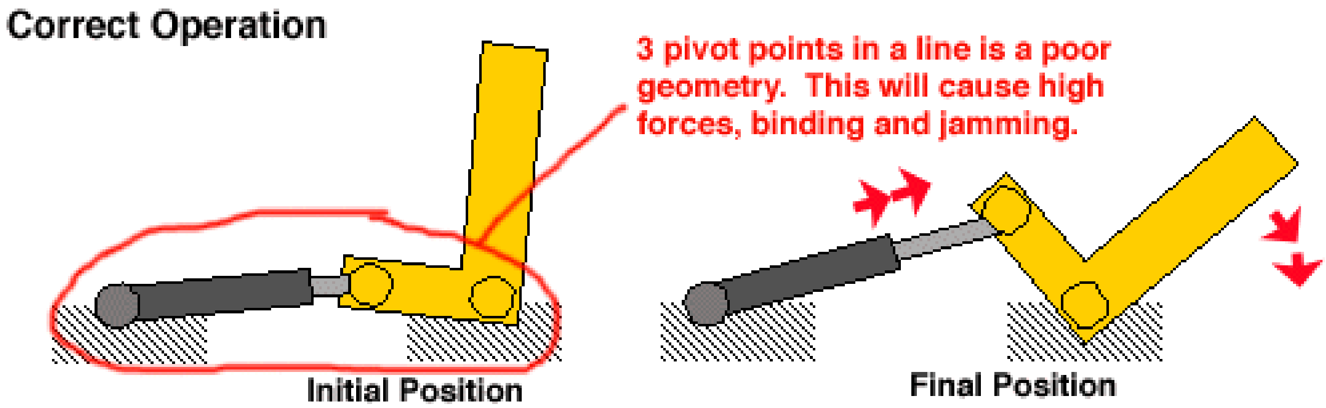
Binding is caused by too much friction, i.e. high forces on the bearings, and not enough leverage due to geometry.

Jamming is when the geometry is in an unstable state and moves the wrong way, then it almost certainly stops moving.

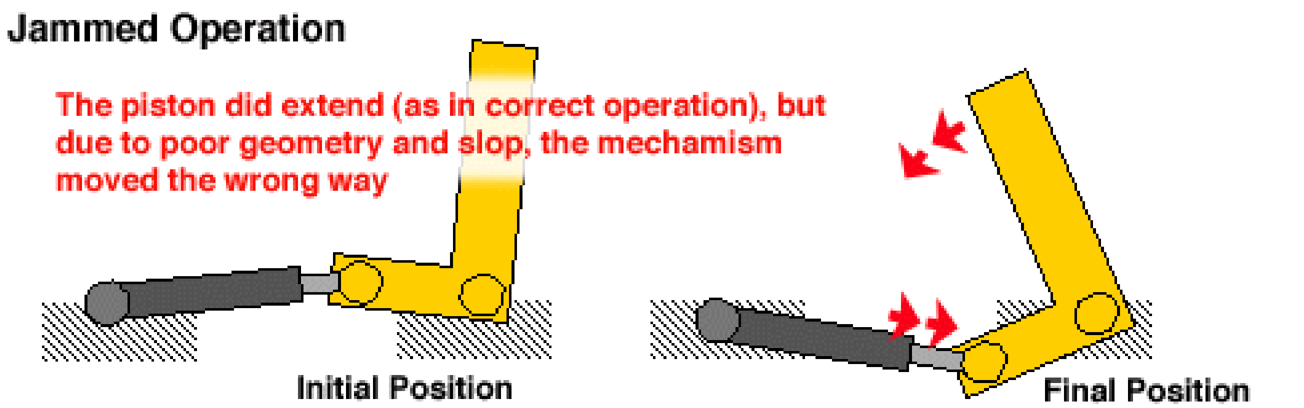


Below is a very badly designed mechanism. The angle between the piston and the linkage is way too small. Obviously if the piston were horizonal it would be impossible to predict which way the linkage would move. A small angle like the one shown is not enough. In addition to providing extremely little torque to rotate the linkage, if there is any slop or flexibility in the system the linkage could be flipped the wrong way and jam.

Below the the intened operation and the likely jammed operation are shown.



Mechanism operating without getting jammed.

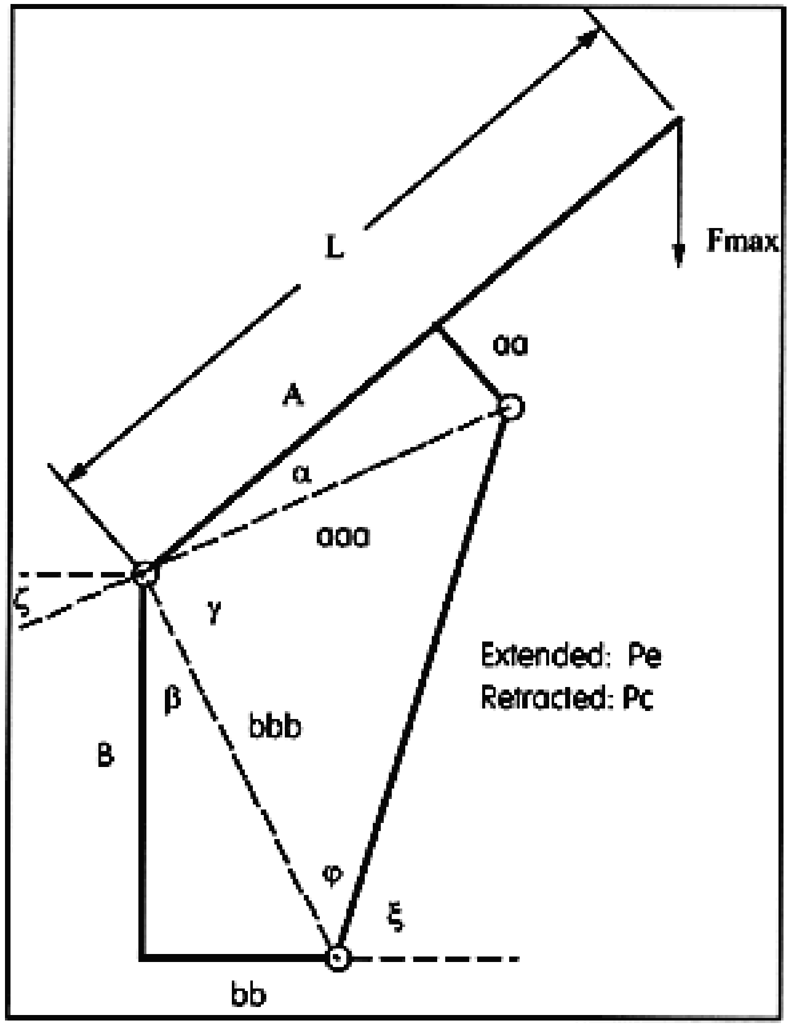


Mechanism jammed after traveling the wrong way.

The Spreadsheet:

The spreadsheet below can be used to evaluate the various parameters of a piston arm assembly. Make sure you are consistent in your units. **Remember this spreadsheet assumes frictionless bearings and a rigid structure.**

Download the piston.xls spreadsheet


L
Fmax
aa
A
α
aaa
ζ
γ
Extended: Pe
Retracted: Pc
β
bbb
B
φ
ξ
bb

PISTONS.XLS

	A	B	C	D	E	F
1	**Spreadsheet to determine range of motion**					
2	**and torque on an arm actuated by a piston**					
3	**Written 12/20/97 by Alex Slocum**					
4						
5	**Inputs: enter numbers in bold**					
6	Boom length, L	**10**				
7	Arm length, A	**6**				
8	offset, aa	**1**				
9	Elevation offset, B	**3**				
10	offset, bb	**1**				
11	Piston length extended, Pe	**6**				
12	Piston length contracted, Pc	**3**				
13	Piston diameter, dp	**0.5**				
14	Supply pressure, Ps	**60**				
15						
16	**Outputs**					
17	Piston area, Ap	0.20				
18	Piston force, Fp	11.8				
19						
20	calculated values					
21	aaa	6.083		0.031772303		
22	bbb	3.162		0.561203097		
23	beta (rad, deg)	0.322	18.4			
24	alpha (rad, deg)	0.165	9.5			
25						
26	**Extended state**			**Contracted state**		
27	gampex (rad, deg), γ	1.281	73.4	gampc (rad, deg)	0.157	9.0
28	gamex (rad, deg)	1.768	101.3	gamc (rad, deg)	0.644	36.9
29	psie (rad, deg), φ	1.331	76.3	psic (rad, deg)	2.820	161.6
30	xse (rad, deg), ξ	0.561	32.2	xsc (rad, deg)	-0.927	-53.1
31	zetae (rad, deg)	0.032	1.8	zetac (rad, deg)	-1.092	-62.6
32	Fhe	9.974		Fhc	7.069	
33	Fve	6.270		Fvc	-9.425	
34	Rhe	6.080		Rhc	2.800	
35	Rve	0.193		Rvc	-5.400	
36	Torque_extended_piston	36.2		Torque_contracted_piston	11.781	
37	Boom angle from horizontal	0.197	11.3	Boom angle from horizontal	-0.927	-53.1
38	Fmax	3.69		Fmax	1.96	