Chapter 1
Mechanisms and Machines: Basic Concepts

1.1 a. The ball-joint (spherical pair) has three degrees-of-freedom, the prismatic pair one, and the cylindrical pair two. The number of degrees-of-freedom of the spatial linkage is given by

$$DF_{\langle spatial \rangle} = 6(n_L - n_J - 1) + \Sigma f_i$$

$$= 6(4 - 3 - 1) + 3 + 1 + 2$$

$$= 6 \text{ degrees-of-freedom}$$

(We do not need the inequality sign for this open-loop chain).

b. Treating the construction equipment schmatic as a spatial linkage:

$$DF_{\langle spatial \rangle} \geq 6(n_L - n_J - 1) + \Sigma f_i$$

$$\geq 6(9 - 11 - 1) + 9 + 2 \times 2$$

$$DF_{\langle spatial \rangle} \geq -5$$

c. Treating the construction equipment schematic as a planar linkage, where a sliding pair has only one degree-of-freedom in plane motion:

$$DF_{\langle planar \rangle} = 3(n_L - n_J - 1) + \Sigma f_i$$

$$DF_{\langle planar \rangle} = 3(9 - 11 - 1) + 9 + 2$$

$$DF_{\langle planar \rangle} = 2$$

d. The planar motion assumption applies if motion occurs in a plane or in a set of parallel planes. The planes of motion of the links must all be parallel. The revolute joint axes must be perpendicular to those planes. These conditions do apply to the construction machinery. The operator controls the linkage via the two hydraulic cylinders.

1.2(a) For the linkage as sketched originally,

$DF = 3(n_L-1) - 2n_{J'} = 3(9-1) - 2x12 = 0$

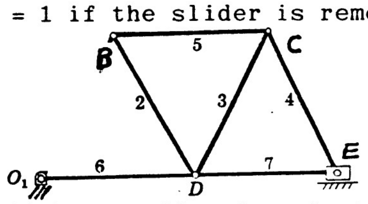
a) Removing any single link (one through seven) reduces n_L by one and $n_{J'}$ by two from which

$DF = 3(8-1) - 2x10 = 1.$

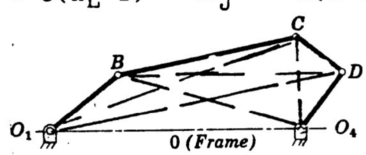
b) Also, we obtain DF = 1 by removing links 1, 2 and 5; or 3, 4 and 5; or 1, 2, 3, 4, and 5.

c) DF = 1 if all links are removed except link 1, or 6 or the slider.

d) DF = 1 if the slider is removed, but the joint at E retained.



1.2(b) Add one link extending from O_1 to C, or B to D, or C to O_4, or B to O_4, or O_1 to D. Then, $DF = 3(n_L-1) - 2n_J' = 3(6-1) - 2x7 = 1.$



1.3 Stroke length S = 2R.

$v_{(avg)} = 2Sn = 2(4 \text{ in})(3000 \text{ rev/min}) = 24{,}000 \text{ in/min or } 400 \text{ in/sec}).$

1.4 R = 2, L = 4, E = 1 in. $\omega = \frac{2\pi}{60}(3000) = 314$ rad/sec

Referring to fig. 1.16

$\phi_1 = \arcsin E/(L-R) = 30^o.$

$\phi_2 = \arcsin E/(L+R) = 9.6^o.$

$\alpha = 180^o + \phi_1 - \phi_2 = 200.4^o$ or 3.50 rad.

$\beta = 180^o - \phi_1 + \phi_2 = 159.6^o$ or 2.79 rad.

Stroke $S = [(L+R)^2 - E^2]^{1/2} - [(L-R)^2 - E^2]^{1/2} = 4.184$ in.

"Forward" stroke time $t_1 = \alpha/\omega = 0.01114$ sec. $v_{1(avg)} = S/t_1 = 375.5$ in/sec.

"Return" stroke time $t_2 = \beta/\omega = 0.00889$ sec. $v_{2(avg)} = S/t_2 = 470.6$ in/sec.

1.5 (see 1.4) $\phi_1 = 48.5^o$, $\phi_2 = 14.5^o$, $\alpha = 3.73$ rad, $\beta = 2.55$ rad.

$S = 4.49$ in, $t_1 = 0.01187$ sec, $v_{1(avg)} = 378$ in/sec.

$t_2 = 0.00812$ sec, $v_{2(avg)} = 553$ in/sec.

1.6 $\omega = 3000\ \pi/30 = 314.16$ rad/s

$$\phi_1 = \arcsin\ (E/(L-R))$$
$$= \arcsin\ (50/(200-100)) = .5236 \text{ rad}$$
$$\phi_2 = \arcsin\ (E/(L+R))$$
$$= \arcsin\ (50/(200+100)) = .1674 \text{ rad}$$

$\alpha = \pi + \phi_1 - \phi_2 = 3.4977$ rad $\quad \beta = \pi - \phi_1 + \phi_2 = 2.7854$ rad

Forward stroke time $t_1 = \alpha/\omega = .01113$ s.

Return stroke time $t_2 = \beta/\omega = .008866$ s.

Stroke $S = \sqrt{(L+R)^2 - E^2} - \sqrt{(L-R)^2 - E^2} = 209.20$ mm

Avg. vel. forward $v_{1(avg)} = S/t_1 = 18790$ mm/s

Avg. vel. return $v_{2(avg)} = S/t_2 = 23595$ mm/s

1.7 The crank and connecting rod positions are determined as in the flow chart. The linkage skeleton diagram is shown on the sketch for L/R=1.5, E/R=0.2 where crank angle T_1 varies from 0^o to 340^o in 20^o steps.

Angles T_1 and T_2 and slider location X_2 are tabulated below for R=1:

T1	T2	X2
0	-7.66225566877	2.48660687473
20	5.43290764513	2.43295424518
40	17.1690352815	2.19920149468
60	26.3634597467	1.84402758957
80	31.5474944957	1.45195830359
100	31.5474944957	1.12466195325
120	26.3634597467	0.844227589566
140	17.1690352815	0.667112607638
160	5.43290764513	0.553569803609
180	-7.66225566876	0.4866026874732
200	-21.1829283574	0.438954641475
220	-34.1844166885	0.474805686816
240	-45.2985623587	0.555267662011
260	-52.1735359216	0.746259740205
280	-52.1735359216	1.09355610154
300	-45.2985623587	1.55526766231
320	-34.1844166865	2.00069457325
340	-21.1829283574	2.33833968325
360	-7.66225566877	2.48660687473