Solutions Manual

Web Enhanced

Mechanism Design

Analysis and Synthesis Volume I

Fourth Edition

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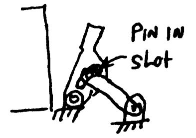
1.2 a) This is a four-bar linkage

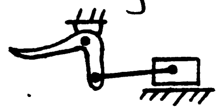
b) Motion generation. The "output" link is path and angle of the drum striker

c)



1.3 a) Function generation. Input handle moves output shear slider

b)



c) four-bar slider

1.4 a) Watt II, the two ternary links are connected together and a ternary link is ground

b) Function generation. The input and output links are pinned to ground.

1.5 a) Motion generation. The output link is not adjacent to ground. Also, the orientation of the window during its motion is of interest, it must move straight out away from the sill before it can rotate to its final position.

b) There are 6 links and 7 f_1 pin joints.

$$F = 3(6-1) - 2(7) = 15 - 14 = +1$$

c) Stephenson I, the two ternary links are not adjacent to each other. Also, the ground link is a binary connected to two ternary links.

1.6 An adjustable four bar linkage

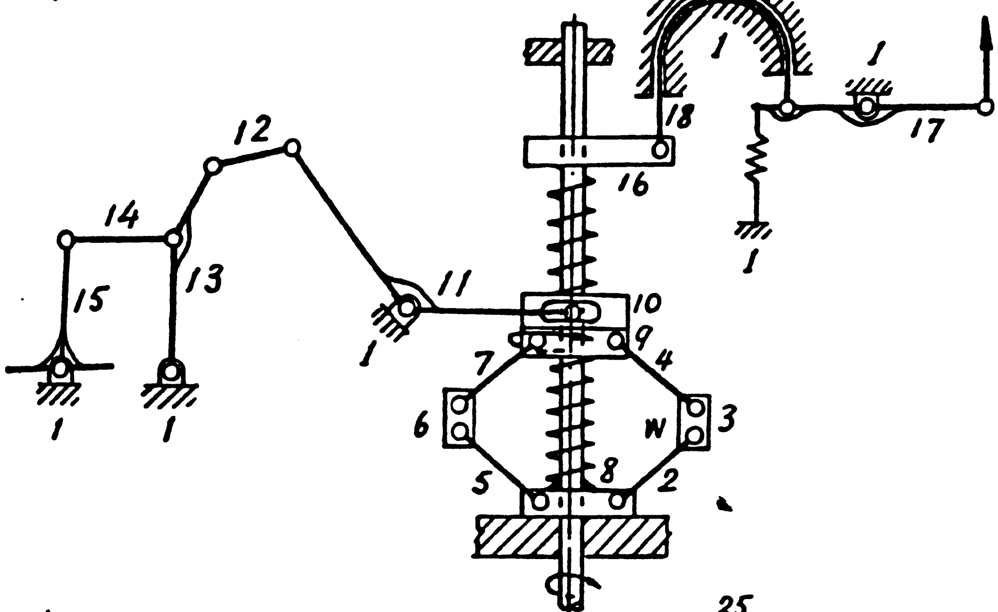
Function generation. Although the input link is not adjacent to ground, the output link is. Also, the task is to move the output link to a closed position when the input link is moved.

Because the output link must be moved first by larger then smaller angles per increment of input rotation of the handle in order to grip the workpiece quickly and to get a high force amplification between the vice jaws and the handle.

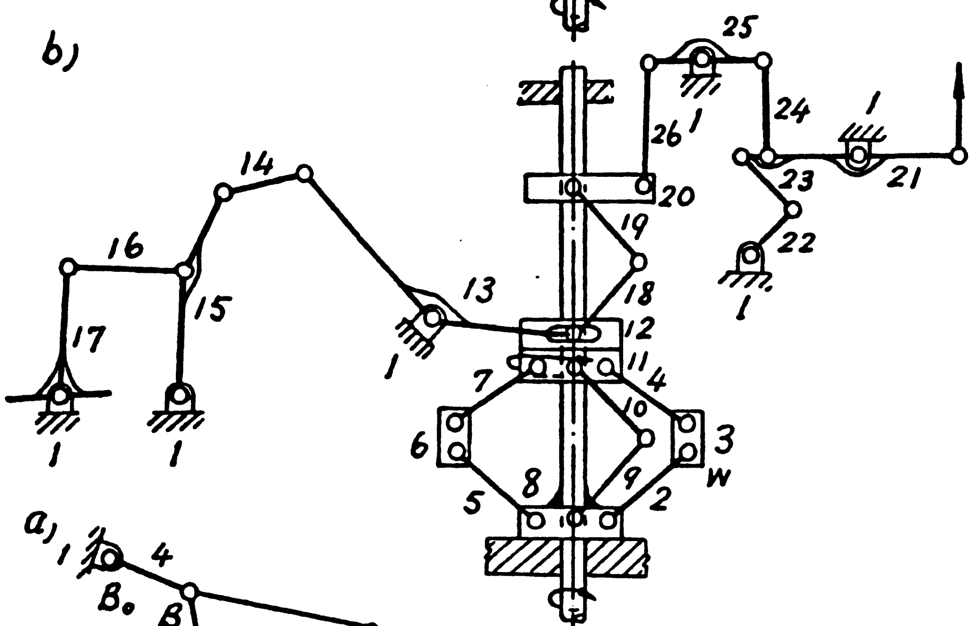
The function of the adjusting screw is to make the vice grips to be able to clamp the different size workpieces with approximately the same force amplification. It is located in the base link, because changing the length of the base link is the best way in which the force amplification can be kept approximately the same for different size workpieces.

1.7 Function generation, both the input and output links are pinned to ground. Because the output link must rotate in a prescribed relationship with the input link.

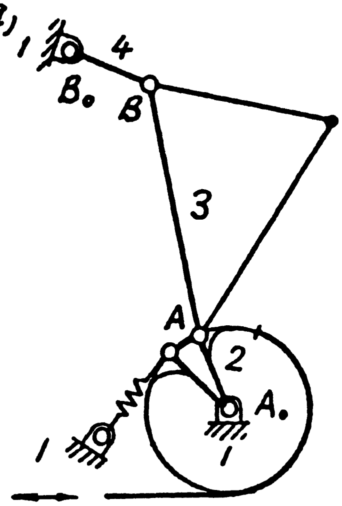
1.8 a)



b)

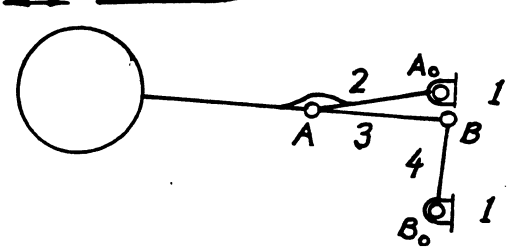


1.9 a)



b) A path generator linkage

1.10 a)



b) A function generator input and output links are pinned to ground.

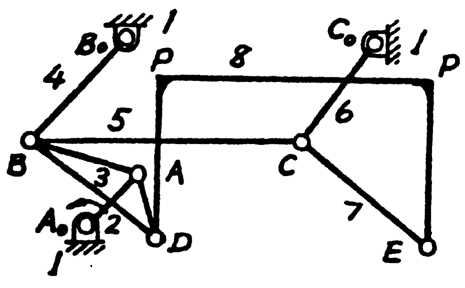
1.11 a) A motion generator

b) Because a linkage can work in the adverse circumstances.

c) Stability in running of the car, since it guides the wheels straight up and down as the car runs over an uneven road.

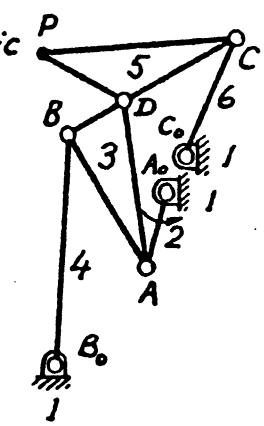
1.12 a) A four bar linkage b) Function generation

1.13 a)



The kinematic diagram of the linkage shown in Fig. P1-13

The kinematic diagram of the linkage shown in Fig. P1-14



b) Stephenson III

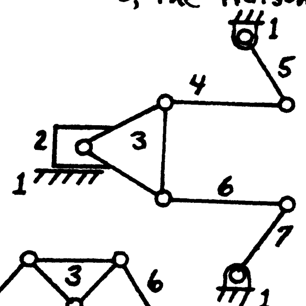
1.14 a) For the linkage shown in Fig. P1.15 Function generation

For the linkage shown in Fig. P1.16 Motion generation, jaws move parallel

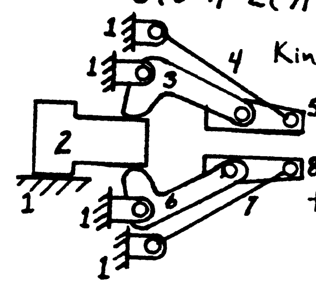
b) $F = 3(7-1) - 2(8) = +2$

$F = 3(8-1) - 2(9) - 1(2) = +1$

c) None, the "Watson" 7-bar

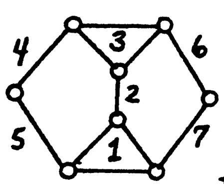


Kinematic diagram of Fig. P1.15

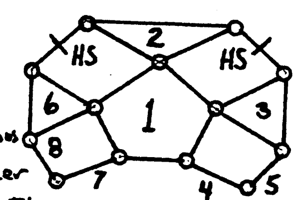


Kinematic diagram of Fig. P1.16

Note that links 3 and 6 are ternaries, necessary if motion is to be transmitted to links 5 and 8.

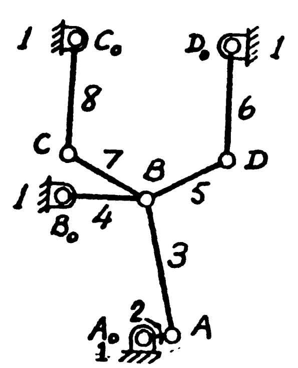


Basic Kinematic Chain of Fig. P1.15 is of the "Watson" 7-bar



Basic Kinematic Chain of Fig. P1.16. "HS" is fictitious link which replaces higher pair slider gear joint. This topology consists of 3 concatenated Watt II six-bar linkages.

1.15 a)



b) By Gruebler's equation:

$n = 8$

$P = 10$

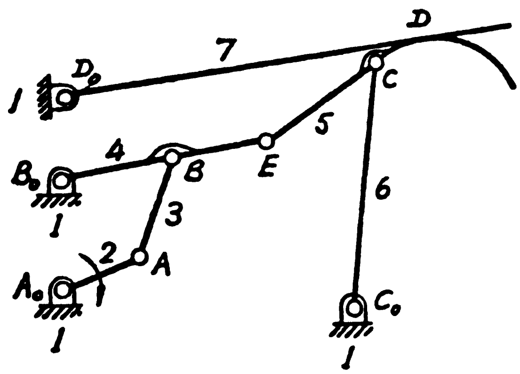
$F = 3(8-1) - 2 \times 10$

$= 1$

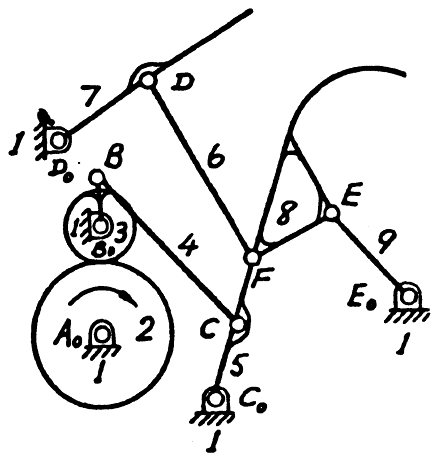
1.15 b) By intuition:

Links 1 through 4 form a four-bar linkage which has a single degree of freedom. Once the input rotation of link 2 is specified, the position of point B is known with respect to A_0, B_0, C_0 and D_0. BCC_0 and BDD_0 form two "rigid" triangles respectively and the mechanism is entirely specified.

1.16 a)



Harvey linkage



Bjorklund linkage

b) $n=7$	$n=9$
$P=8$	$P=11$
$S=1$	$S=1$
$F=3(7-1)-2\times 8-1=1$	$F=3(9-1)-2\times 11-1=1$

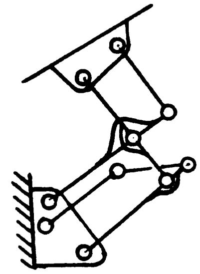
c) Watt II; Motion generation.

1.17 a) Stephenson I b) Motion generation

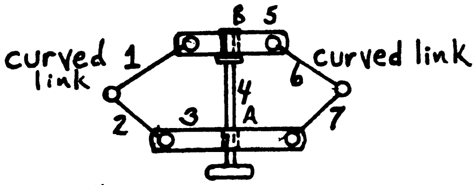
1.18 a) Watt II b) Function generation

c) Because greater angles of output oscillation are wanted than possible with a four-bar linkage, in order to get complete agitation.

1.19 a) Watt I b)



1.20 a) If the open chain retractor ends are neglected the Kinematic diagram would be:



Kinematic diagram of Fig P1.30

$DoF = 3(7-1) - 2(8) = +2$

Joint A is a screw pair, 1 DOF

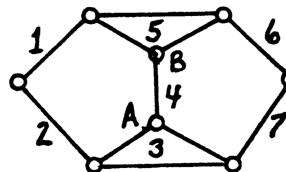
Joint B is a revolute pair, 1 DOF

Due to the screw pair, this mechanism cannot be backdriven.

This is actually a 2½ dimension linkage, 2-D joints distributed in a 3-D manner.

The 2 freedoms come from using the 2-D grübler equation in 2½ D space. One freedom reflects the internal planar motion and the second is from an out-of-plane motion.

b) c) There are no six-bar mechanisms in this 7-bar "Watson" topology regardless of which links, either 1 or 4 or any others, are grounded

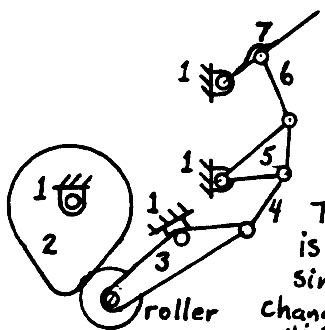


BKC of "Watson" 7-bar linkage

Note that the axes of joints A and B have been turned 90° into the plane.

1.21 a) Function generation, input and output links are pinned to ground

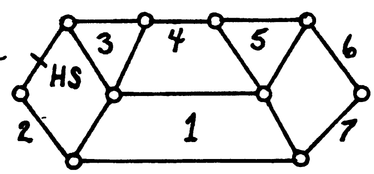
b)



Kinematic diagram of Fig. P1.31

The roller link is not counted since it merely changes sliding into rolling motion.

Basic Kinematic Chain of Fig. P1.31



"HS" is a fictitious link meant to model the f_2 higher pair sliding joint between links 2 and 3 or the roller link, which is supposed to allow a rolling motion, f_1 joint.

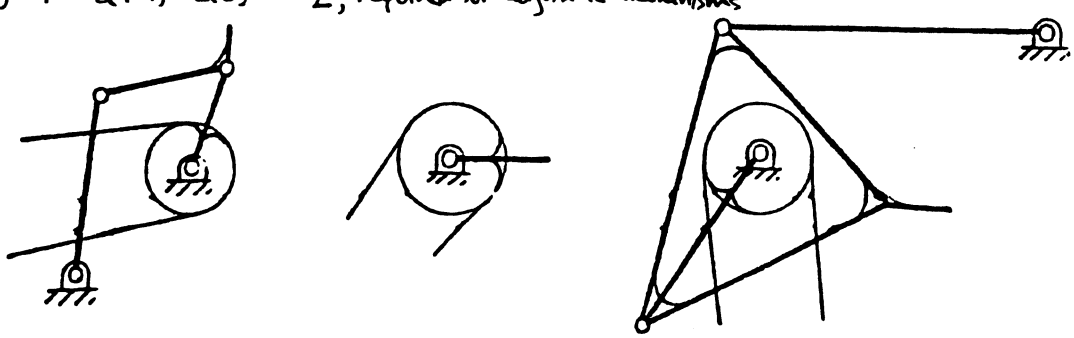
c) There are 2 Watt II six-bar linkages melded together sharing links 3, 4 and 5

d) Six (and this eight-bar) link mechanisms with the Watt II topology allow a very large output link rotation (here 180°) while preserving good transmission angles and good motion characteristics in general.

1.22 a) This question strikes the heart of how we analyze multiple-jointed linkages; note that there is no definitive ruling on this question. It could be either a WATT I or Stephenson III. The WATT II enjoys a slight edge because it's topology is of 2 4-bars, which is what we see here.

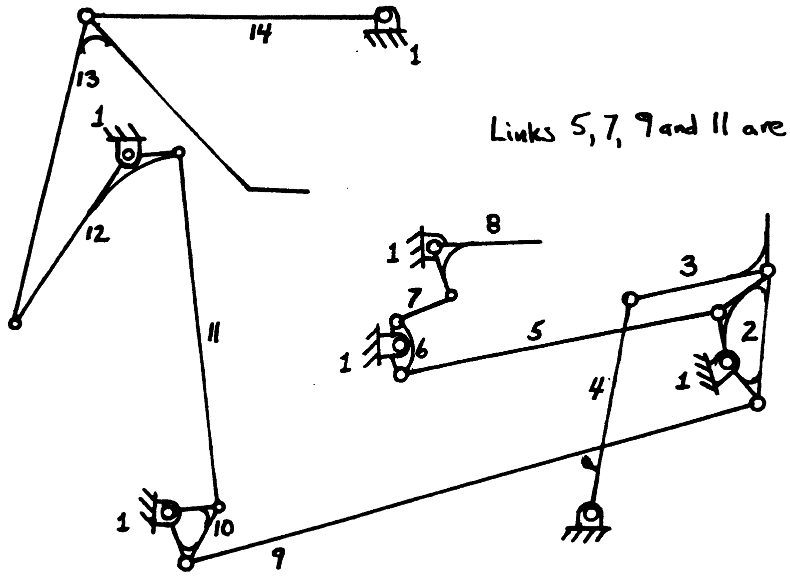
b) $F = 3(7-1) - 2(8) = +2$, required for adjustable mechanisms

1.23 a)



(1) Step 1 Step 2 Step 3

(2)

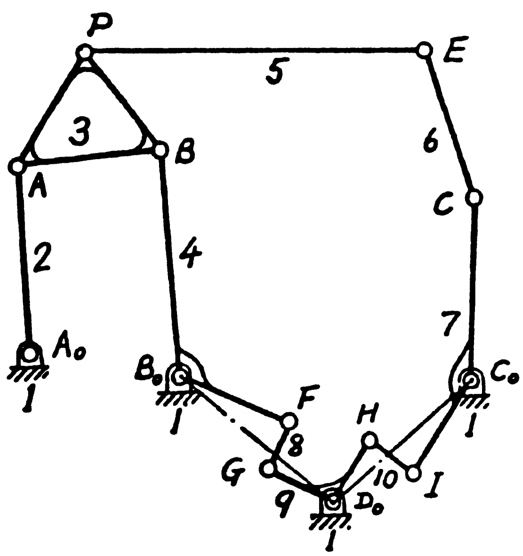


Links 5, 7, 9 and 11 are the drive belts.

1.23 b) Step 1 : Path generation
Step 2 : Motion generation
Step 3 : Motion generation

c) $F = 3(14-1) - 2(19) = +1$

1.24 a)



b) $n = 8$

$p = 9$

$s = 2$

$F = 3(8-1) - 2\times 9 - 1\times 2 = 1$

$n' = 10$

$p' = 13$

$F' = 3(10-1) - 2\times 13 = 1$

$F' = F$

1.25 a) Stephenson III

b) The kinematic diagram is drawn on next page.

(1) The range of rotation of the input link is $\Delta\phi$.

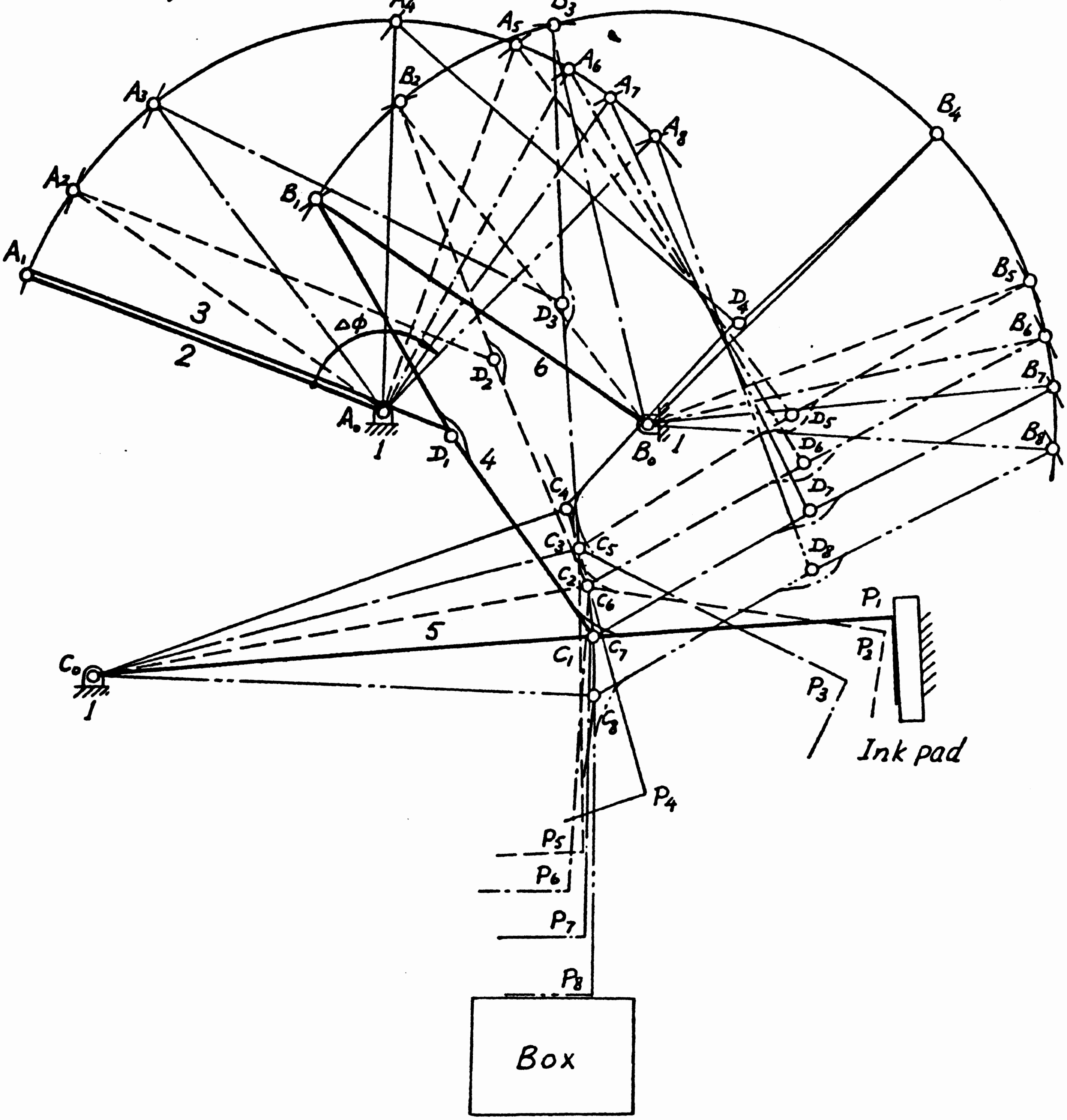
(2) The linkage indeed does hit the ink pad and produce an approximate straight line, approaching to and receding from the box.

c) Yes.

Because it can satisfy the requirements of motion with a minimum number of links.

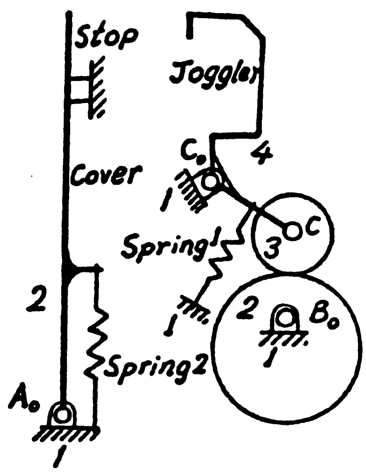
d) If $|L_3 - L_2| < (S_{A_0 - D_i})_{min}$, the range of rotation of the input link would be changed. If $|L_3 - L_2| > (S_{A_0 - D_i})_{min}$, the linkage would not hit the ink pad, (cont'd on p.8)

1.25 b)

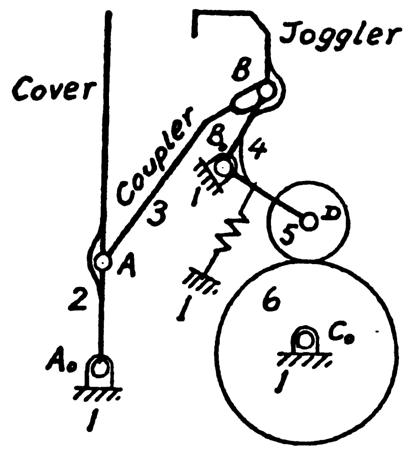


where L_3 and L_2 are the lengths of link 3 and link 2 respectively; $(S_{A_0-D_i})_{min}$ is the shortest distance from the input pivot A_0 to the locus of joint D between the initial and final positions.

1.26 a)



b)



b) A coupler is added between the cover and the joggler, and the stop and spring 2 are removed.

c) For Fig. P1-32 (Part a)):

For the cover: $n=2 \quad P=1$

$$F = 3(2-1) - 2 \times 1$$
$$= 1$$

For the joggler: $n=4 \quad p=3 \quad s=1$

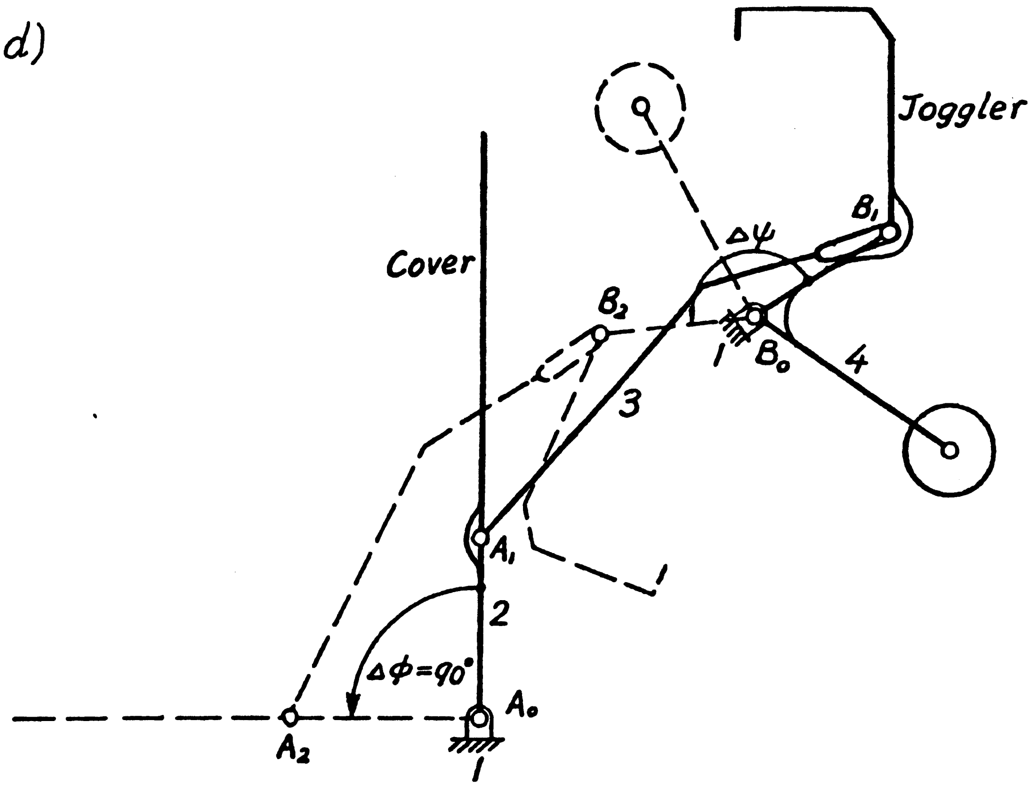
$$F = 3(4-1) - 2 \times 3 - 1$$
$$= 2$$ (One of them is redundant)

For Fig. P1-33 (Part b))

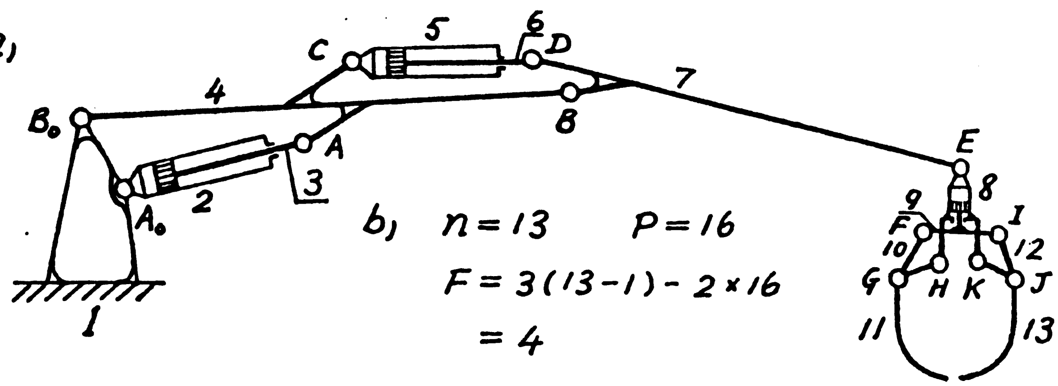
$n=6 \quad P=5 \quad S=2$

$$F = 3(6-1) - 2 \times 5 - 2$$
$$= 3$$ (One of them is redundant)

1.26 d)



1.27 a)

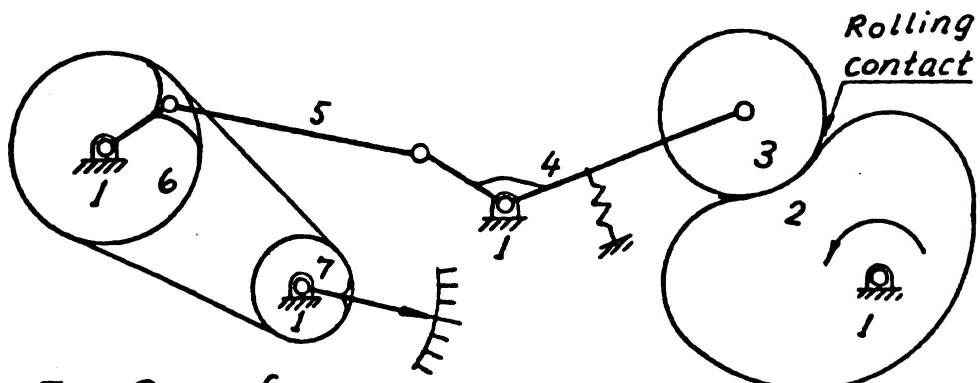


b) $n=13 \qquad P=16$

$F=3(13-1)-2\times 16$

$=4$

1.28 a)



b) $n=7 \qquad P=8$

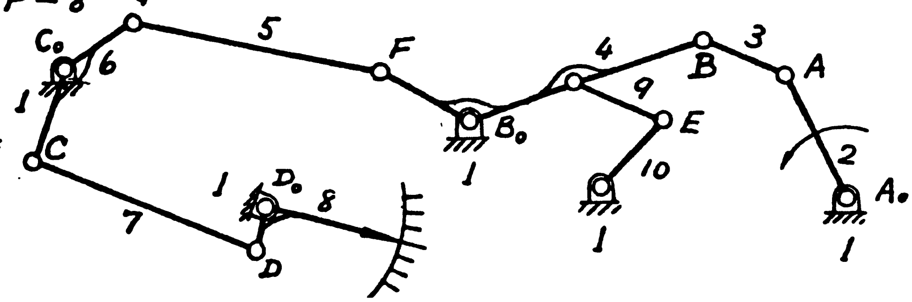
$s=1 \qquad F=$

$3(7-1)-2\times 8-1=1$

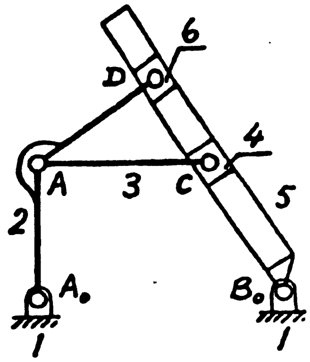
$n'=10,\ P'=13,\ F'=$

$3(10-1)-2\times 13=1$

$F'=F$



1.29 a)



b) For the original linkage:

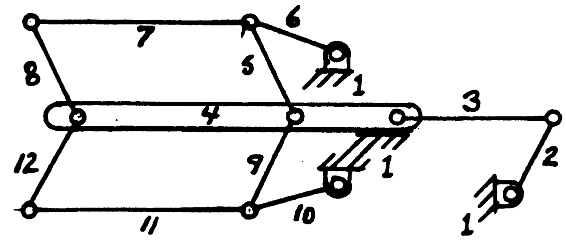
$n=4 \quad P=3 \quad S=2$

$F=3(4-1)-2\times3-2=1$

For the lower pair equivalent linkage: $n'=6 \quad P'=7$

$F'=3(6-1)-2\times7=1=F$

1.30 a)

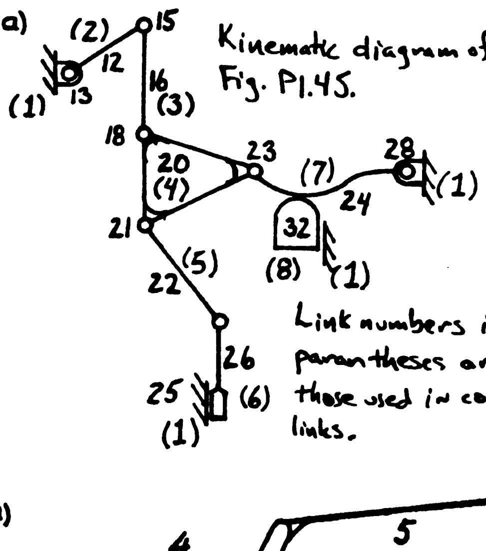


Kinematic diagram of Fig. P1.44

b) $F=3(12-1)-2(16)=+1$

Link 2 is the input link and links 7 and 11 are the output. Note that link 4 slides on link 1, this is to not allow the dilator blades to be forced as a complete unit into a sideways motion while in use. Also, the slot in link 4 is to allow links 5 and 9 to collapse into a smaller volume, it is only a clearence slot, not an f_2 slider slot.

1.31 a)



Kinematic diagram of Fig. P1.45.

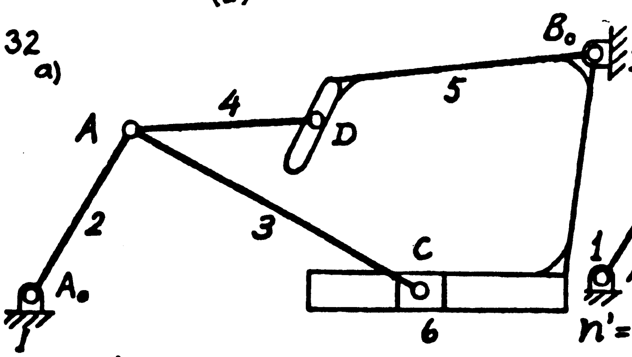
Link numbers in parantheses are those used in counting links.

b) The joint between links 25 and 26 is an f_1 sliding joint. The flexible hose joint between links 22 and 26 is modelled as an f_1 pin joint.

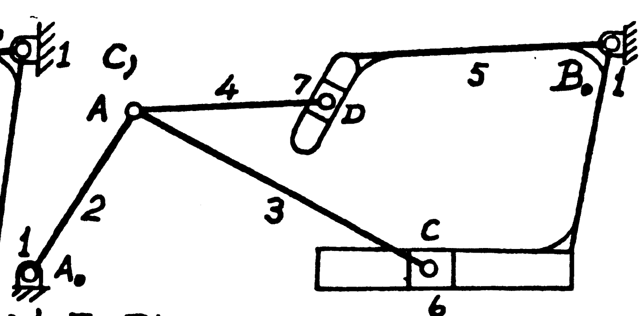
c) $F=3(8-1)-2(9)-1(1)=+2$

The two inputs are:
- drive shaft 13, and
- swing-arm 24.

1.32 a)



c)



$n'=7, \; P'=8, \; F'=3(7-1)-2\times8=2=F$

b) $n=6, \; P=6, \; S=1 \quad F=3(6-1)-2(6)-1(1)=+2$

1.33 a) In this case $F=2$ and $n=J$ since binary chains are made up of equal numbers of links and joints. Then:

$$2 = 3(x-1) - 2x \qquad \text{or} \qquad x = 5.$$ Five binary links and Five f_1 joints

b) From part a) the answer is 5. However, this gives us no insight into why 5 is the answer and if it is the answer for all $F=2$ mechanisms. The binary chains are the least complex mechanisms for any degree of freedom and we found that 5 binaries created a 2 DoF mechanism in part a) so 5 is the answer.

c) From grüblers equation : $2 = 3(n-1) - 2J$ and $n=J=5$ is not allowed.

then: $J = \frac{3n}{2} - \frac{5}{2}$ and n and J must be integers. Therefore, note that n must be odd. The next odd number after 5 is 7 so:

$n = 7$, $J = 8$

1.34 A 10 link, 2 DoF mechanism with all f_1 joints is impossible from part c) of problem 1.33.

a) If $F=2$ and $n=9$ then $f_1 = 11$. 11 joint pairs must be purchased or designed.

b) Parts b) and c) have 2 answers depending upon what type of topologies are allowed. This discussion requires recognizing that J joints have 2J joint nodes, where 2 nodes on 2 separate links make up one joint pair. The immediate solution to this problem would be to reason: 11 joints equals 22 joint nodes distributed among 9 links. If all links are binaries, then 18 nodes are required leaving 4 extra nodes to be used in creating "higher-order" links, those larger than a binary. Grouping all 4 extra nodes onto one binary link creates 1 hexagonal link (6-sided) and 8 binaries. We could "spread" these extra nodes around to form 5 distinct sets of links: 1 hexagonal, 8 binaries; 1 Pentagonal, 1 Ternary, 7 binaries; 2 quaternary, 7 binaries; 1 Quaternary, 2 Ternary, 6 binaries; 4 Ternaries, 5 binaries. The 1H, 8B solution suffers from "fractionated freedom", the entire mechanism does not move as a whole. The first "total freedom" solution is 2Q, 7B. Answers:

	Fractionated	Total
b)	6	4
c)	1	2

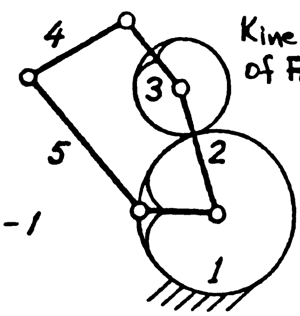
1.35

$n = 5$

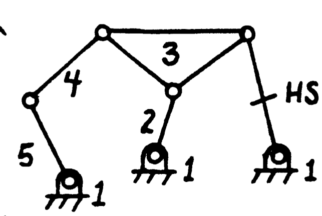
$p = 5$

$s = 1$

$F = 3(5-1) - 2 \times 5 - 1$
$= 1$



Kinematic diagram of Fig. P1.47



Basic Kinematic Chain of Fig. P1.47 is a Stephenson III chain. "HS" designates higher-pair sliding f_2 joint

1.36 For Fig. P1.48: $n=9$ $p=11$ $F=3(9-1)-2\times 11=2.$

HGC is a slider crank with one degree of freedom.

FEDCBAJ is a Watt II linkage with one degree of freedom: total is two degrees of freedom.

For Fig. P1.49: $n=8$ $p=8$ $s=1$ $F=3(8-1)-2\times 8-1=4.$

ABCEFG is a single loop with 7 links. It has 4 degrees of freedom. When the positions of points C and E are known, the position of slider D is known. Therefore, the entire mechanism has 4 degrees of freedom.

For Fig. P1.50: $n=8$ $p=10$ $F=3(8-1)-2\times 10 = 1.$

Replace the belt by a binary link between pulley A and B forming a 4-bar. Then, when the rotation of pulley A is specified, the positions of points C and G are known. Then, rigid triangle DEF is specified. Therefore, the mechanism has one degree of freedom.

For Fig. P1.51: $n=6$ $p=7$ $F=3(6-1)-2\times 7=1$

FED is a slider crank with one degree of freedom. When the rotation of crank FE is specified, the position of point C is known. CAB forms a "rigid" triangle. Then, the linkage is entirely specified.

For Fig. P1.52: $n=12$ $p=15$ $F=3(12-1)-2\times 15=3.$

ABCD and FEGH are four-bar linkages with one degree of freedom each. DIMNJKL is a Stephenson III linkage with one degree of freedom. Total is three degrees of freedom.

For Fig. P1.53: $n=14$ $p=18$ $F=3(14-1)-2\times 18=3;$

or $n=12$ $p=15$ $F=3(12-1)-2\times 15=3.$

IJK is a rigid triangle, which can rotate about pivot K. GHJI is a four-bar linkage with one degree of freedom. We have found two degrees of freedom so far. Furthermore, when IJK and GHJI are fixed and the position of slider D is specified, DFG, DFE, DCE and then ABC form four "rigid" triangles. Therefore, total is three degrees of freedom.

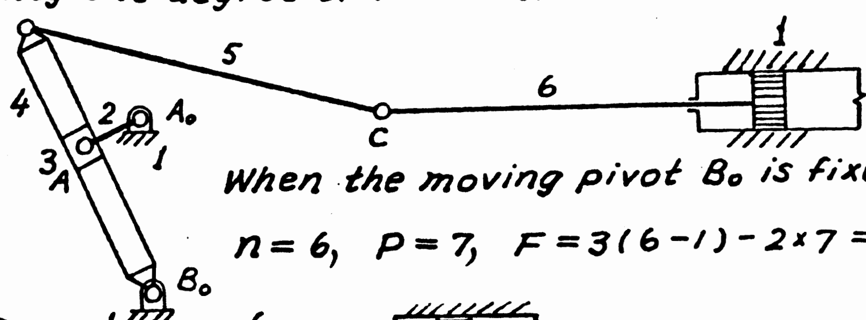
For Fig. P1.54: $n=10$ $P=12$ $F=3(10-1)-2\times12=3$.
ABCDE is a single loop with five links. It has two degrees of freedom. FIJK is a four-bar linkage with one degree of freedom. CGH now forms a "rigid" triangle. Therefore, the entire linkage has three degrees of freedom.

For Fig. P1.55: $n=10$ $P=12$ $F=3(10-1)-2\times12=3$.
Slider A has one degree of freedom itself. ABC and CDE are slider cranks with one degree of freedom each. BFE is now locked. Total, therefore, is three degrees of freedom.

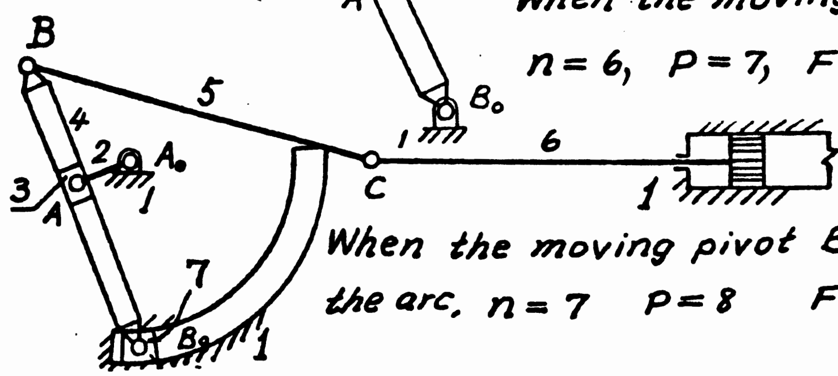
For Fig. P1.56: $n=8$ $P=8$ $S=1$ $F=3(8-1)-2\times8-1=4$.
Slider H has one degree of freedom itself. Point A has two degrees of freedom: one is the translation along the fork, the other is the rotation about the pivot B. ACDEFGH is a Watt I linkage with one degree of freedom. So that total is four degrees of freedom.

For Fig. P1.57: $n=9$ $P=11$ $S=1$ $F=3(9-1)-2\times11-1=1$.
DBFH is a four-bar linkage with one degree of freedom. When DBFH is specified, the positions of the rest of the mechanism are known. Therefore, the linkage has only one degree of freedom.

1.37



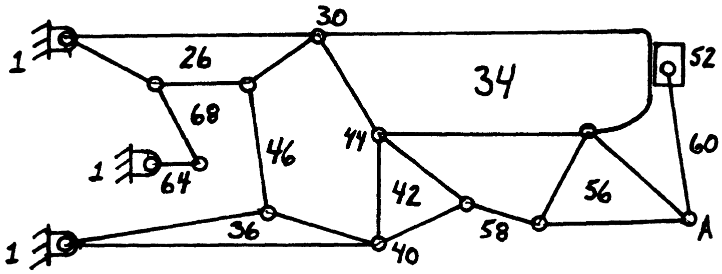
When the moving pivot B_0 is fixed,
$n=6$, $P=7$, $F=3(6-1)-2\times7=1$.



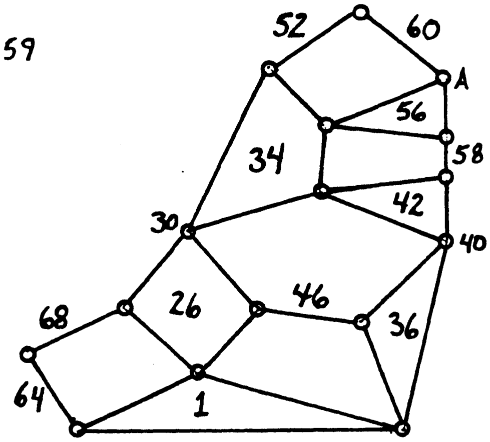
When the moving pivot B_0 is moving along the arc, $n=7$ $P=8$ $F=3(7-1)-2\times8=2$.

1.38 Stephenson III, The ternary links are not connected and a ternary is ground.

1.39 a)



Kinematic diagram of Fig. P1.59



Basic Kinematic Chain of Fig. P1.59

b) There are many four-bar sub-chains. The largest six-bar subchains are:

WATT II: 1, 26, 68, 64, 46, 36

Stephenson I: 1, 26, 46, 36, 34, 42

Watt chain: 34, 56, 42, 58, 60, 52

No link in this last chain is grounded

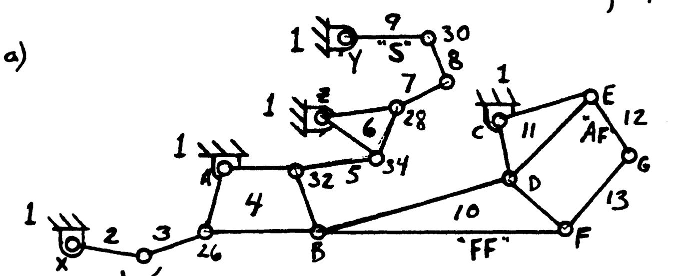
c) There are 4 ternary links.

Numbers: 1, 36, 42, 56

d) $F = 3(12-1) - 2(16) = +1$

Links 1, 26, 46, 36, 68, 64 form a Watt II six-bar 1 DOF chain. Therefore, points 30 and 40 have a specified motion. Links 34, 56, 42, 58, 60, 52 form another Watt chain, so knowing the motion of 40 with respect to 30 allows the motion of 52 on 34 to be found. The linkage is entirely specified. Therefore, 1 degree of freedom.

1.40 a)



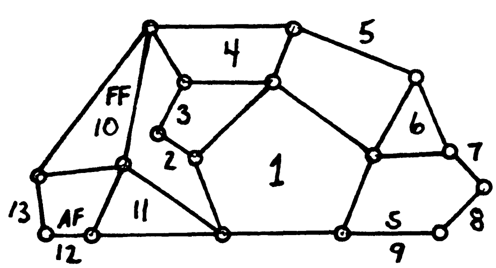
Kinematic diagram of Fig. P1.60

b) WATT II: 1, 2, 3, 4, 5, 6 ; 1, 2, 3, 4, 10, 11

WATT I: 1, 4, 10, 11, 12, 13

WATT II: 1, 4, 5, 6, 10, 11

5-bar: 1, 6, 7, 8, 9

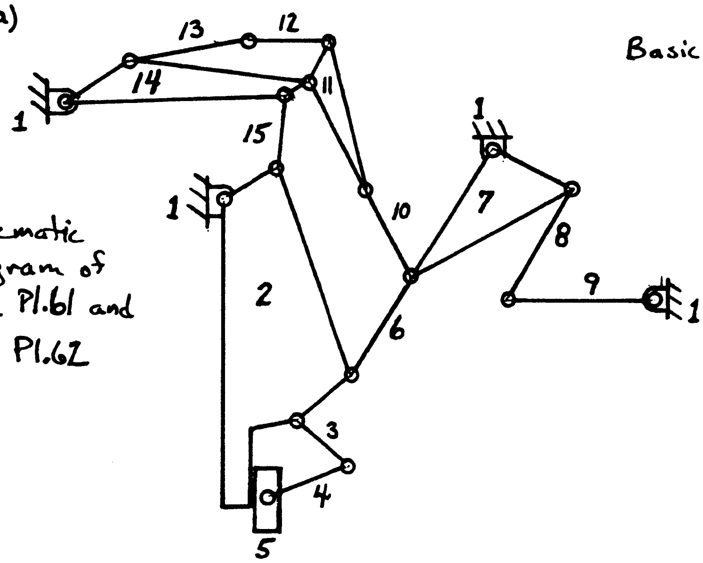


c) There are 3 ternary links: 6, 10, 11

d) $3(13-1) - 2(17) = +2$

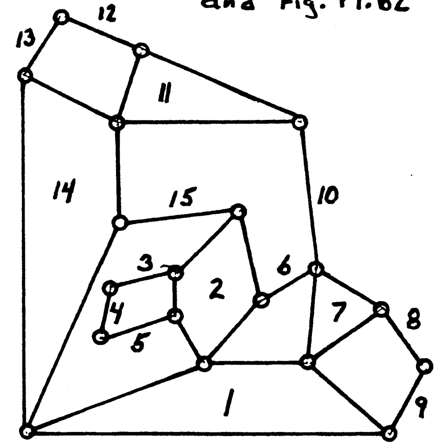
One quick intuitive way is to note there are 2 hydraulic cylinders. Otherwise, links 1, 2, 3, 4, 5, 6 form a WATT II. This specifies the motion of point B and links 10, 11, 12, 13. This leaves only links 7, 8, 9 which along with 1 and 6 form a 5 bar requiring 1 more input. So, 2 DOF.

1.41 a)



Kinematic diagram of Fig. P1.61 and Fig. P1.62

Basic Kinematic Chain of Fig. P1.61 and Fig. P1.62



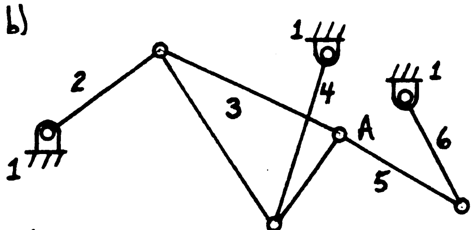
b) $F = 3(15-1) - 2(20) = +2$

The two freedoms are the control cylinder which moves the linkage between the deployed and stowed positions, modelled by links 12 and 13, and the four-bar slider crank shock absorber linkage on the landing wheel, modelled by links 2, 3, 4 and 5.

c) There are 2 Watt II's consisting of links: 1, 2, 6, 7, 8, 9 and 1, 2, 6, 7, 14, 15

1.42 a) Path generation (the problem statement actually states this!)

b)



Kinematic diagram of Fig. P1.63 and Fig. P1.64

c) $F = 3(6-1) - 2(7) = +1$

Links 1, 2, 3, 4 form a 1 DoF fourbar linkage. This specifies the motion of point A. Adding a dyad (two binary links in a row) to any mechanism does not change the DoF so, it is +1.

Or, weld link 2 to 1. This takes away 1 DoF. Now links 12, 3, 4 form a structural triangle and is all grounded. Therefore point A is grounded. This leaves links 1234, 5, 6 which also forms a triangle with zero DoF. The entire linkage is grounded. Since we took away only 1 DoF, the original linkage must have +1.

d) This is a Stephenson III linkage, the ternary links are not joined together and a ternary link is grounded.

e) The Watt I, Stephenson I and Stephenson II linkages may satisfy this task.

1.43 Fig. P1.65

a) Function generation

b) $F = 3(5-1) - 2(5) - 1(1) = +1$

Ground the slider link. This fixes point B. Then the connecting rod-planet gear link (all one link), input crank, and ground form a triangle. The mechanism is completely fixed. Therefore, the original mechanism had +1 DoF.

c) This is a Stephenson III linkage

Fig. P1.66

a) Function generation

b) $F = 3(4-1) - 2(4) = +1$

Ground any other link, either A-C or DF. A triangular structure results. Therefore, the original mechanism had +1 DoF

c) This is a four-bar crank-slider linkage

Fig. P1.67

a) Function generation

b) $F = 3(6-1) - 2(7) = +1$

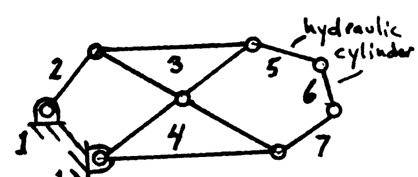
Ground slider link C. This forms a triangle between ground link D-C, the handle link from D to the cross-shaped slider, and the cross-shaped slider. This fixes point B. The cylinder between A-B is also fixed. Therefore, the original mechanism had +1 DoF.

c) This is a Stephenson III linkage

Fig P1.68

a) Motion generation

b) $F = 3(7-1) - 2(8) = +2$



Kinematic diagram of Fig. P1.68

Ground link 2. This forms a triangular structure between links 12, 3, 4. However, links 1234, 5, 6, 7 still form a four-bar chain with 1 DoF. Therefore, the original linkage had +2 DoF

c) There is a four-bar formed by links 1, 2, 3, 4. Links 3, 4, 5, 6, 7 form a five-bar binary link chain.