PLC I/O List For Adaptive Vibratory Bowl Feeder
Martin Maher AMT LAB

I/O List For Mitsubishi PLC
One Phase Excitation Clockwise Rotation Step Angle (1.8^0)

List	Description	List	Description
X27	Start Switch (Toggle Switch)	Y0	Step 1: Hybrid Stepping Motor
		Y1	Step 2: Hybrid Stepping Motor
		Y2	Step 3: Hybrid Stepping Motor
		Y3	Step 4: Hybrid Stepping Motor

One Phase Excitation Anticlockwise Rotation Step Angle (1.8^0)

List	Description	List	Description
X27	Start Switch (Toggle Switch)	Y3	Step 1: Hybrid Stepping Motor
		Y2	Step 2: Hybrid Stepping Motor
		Y1	Step 3: Hybrid Stepping Motor
		Y0	Step 4: Hybrid Stepping Motor

Two Phase Excitation Clockwise Rotation Step Angle (1.8^0)

List	Description	List	Description
X27	Start Switch (Toggle Switch)	Y1 & Y3	Step 1: Hybrid Stepping Motor
		Y1 & Y2	Step 2: Hybrid Stepping Motor
		Y0 & Y2	Step 3: Hybrid Stepping Motor
		Y0 & Y3	Step 4: Hybrid Stepping Motor

Two Phase Excitation Anticlockwise Rotation Step Angle (1.8^0)

List	Description	List	Description
X27	Start Switch (Toggle Switch)	Y0 & Y3	Step 1: Hybrid Stepping Motor
		Y0 & Y2	Step 2: Hybrid Stepping Motor
		Y1 & Y2	Step 3: Hybrid Stepping Motor
		Y1 & Y3	Step 4: Hybrid Stepping Motor

One/Two Phase Excitation Anticlockwise Rotation Half Stepping ($.9^0$)

List	Description	List	Description
X27	Start Switch (Toggle Switch)	Y0 & Y2	Step 1: Stepping Motor (Sequence 1)
		Y2	Step 2: Stepping Motor (Sequence 1)
		Y1 & Y2	Step 3: Stepping Motor (Sequence 1)
		Y1	Step 4: Stepping Motor (Sequence 1)
X27	Start Switch (Toggle Switch)	Y1 & Y3	Step 5: Stepping Motor (Sequence 2)
		Y3	Step 6: Stepping Motor (Sequence 2)
		Y0 & Y3	Step 7: Stepping Motor (Sequence 2)
		Y0	Step 8: Stepping Motor (Sequence 2)

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I/O List For Mitsubishi PLC
Wiper Blade Tool

List	Description	List	Description
X0	Vibration Sensor	Y0	Step 1: Hybrid Stepping Motor
X1	Guided Cylinder (Home Position)	Y1	Step 2: Hybrid Stepping Motor
X2	Guided Cylinder (Extended Position)	Y2	Step 3: Hybrid Stepping Motor
X3	Fibre Optic Sensor (Fall Off Rate)	Y3	Step 4: Hybrid Stepping Motor
X4	Fibre Optic Sensor (Fall Off Rate)	Y4	Optional
X5	Fibre Optic Sensor (Fall Off Rate)	Y5	Optional
X6	Photomicrosensor (Encoder Disc Counter)	Y6	Optional
X7	Encoder Disc Fibre Optic Sensor One	Y7	Vibration Bowl Relay
X10	Encoder Disc Fibre Optic Sensor Two	Y10	Air Blast (Clearing Blockages)
X11	Fibre Optic Sensor (Pass-By Rate)	Y11	Optional
X21	Toggle Switch (Resets V & Z Registers)	Y12	Pin Cylinders Out (Angle Lock)
X22	Toggle Switch (Experiments Complete)	Y13	Guided Cylinder Out
X23	Toggle Switch (Height Up)	Y14	Pin Cylinders Out (Height Lock)
X24	Toggle Switch (Angle Change)	Y15	Optional
X27	Toggle Switch (Start PLC Program)	Y17	Flashing Light On

Narrow Track Tool

List	Description	List	Description
X11	Fibre Optic Sensor (Pass-By Rate)	Y6	Pin Cylinder (Narrow Track)
X14	Fibre Optic Sensor (Rejection Rate)	Y7	Vibration Bowl Relay
X21	Toggle Switch (Locks Y12 & Y14)	Y12	Pin Cylinder (Wiper Blade Tool)
X23	Toggle Switch (Locks Pin Cylinder Y6)	Y14	Pin Cylinder (Wiper Blade Tool)
X24	Toggle Switch (Starts Vibration Bowl)	Y16	Optional
X26	Toggle Switch (Resets V & Z Registers)	Y17	Flashing Light On
X27	Toggle Switch (Start PLC Program)	Y20	Optional

Raised Ledge Tool

List	Description	List	Description
X11	Fibre Optic Sensor (Pass-By Rate)	Y6	Pin Cylinder (Narrow Track Tool)
X21	Toggle Switch (Locks Y12, Y14 & Y6)	Y7	Vibration Bowl Relay
X23	Toggle Switch (Locks Pin Cylinder Y11)	Y11	Pin Cylinder (Raised Ledge Tool)
X24	Toggle Switch (Starts Vibration Bowl)	Y12	Pin Cylinder (Wiper Blade Tool)
X26	Toggle Switch (Resets V & Z Registers)	Y14	Pin Cylinder (Wiper Blade Tool)
X27	Toggle Switch (Start PLC Program)	Y17	Flashing Light On

PLC I/O List For Adaptive Vibratory Bowl Feeder
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Wiper Blade Tool
PLC Input Conditions during a Demonstration

Step	Description	X0	X1	X2	X3	X4	X5	X6	X7	X10	X11	X21	X22	X23	X24	X27
0	Start up	On	On		On	On	On		On	On	On					On
1	Operational Mode	On	On		On	On	On		On	On	On					On
2	Exp 1 (Angle 1) (Height 0)	On	On		On	On	On		On	On	On					On
3	Stop Do Calculations		On		On	On	On		On	On	On		On			On
4	Move New Height			On	On	On	On	On			On	On		On		On
5	Operational Mode	On	On		On	On	On				On					On
6	Exp 2 (Angle 1) (Height 1)	On	On		On	On	On				On					On
7	Stop Do Calculations		On		On	On	On				On		On			On
8	Move New Height			On	On	On	On	On			On	On		On		On
9	Operational Mode	On	On		On	On	On				On					On
10	Exp 3 (Angle 1) (Height 2)	On	On		On	On	On				On					On
11	Stop Do Calculations		On		On	On	On				On		On			On
12	Move Back (Height 0)			On	On	On	On	On	On	On	On	On			On	On
13	Move Blade (Angle 2)			On	On	On	On	On			On	On		On		On
14	Operational Mode	On	On		On	On	On				On					On
15	Exp 4 (Angle 2) (Height 0)	On	On		On	On	On				On					On
16	Stop Do Calculations		On		On	On	On				On		On			On
17	Move (Angle 2) (Height 1)			On	On	On	On	On			On	On		On		On
18	Operational Mode	On	On		On	On	On				On					On
19	Exp 5 (Angle 2) (Height 1)	On	On		On	On	On				On					On
20	Stop Do Calculations		On		On	On	On				On		On			On
21	Move (Angle 2) (Height 2)			On	On	On	On	On			On			On		On
22	Operational Mode	On	On		On	On	On				On					On
23	Exp 6 (Angle 2) (Height 2)	On	On		On	On	On				On					On
24	Stop Do Calculations		On		On	On	On				On		On			On
25	Move Zero Height			On	On	On	On	On	On	On	On				On	On
26	Move Zero Angle			On	On	On	On	On	On	On	On				On	On
27	Move Optional Height			On	On	On	On	On			On			On		On
28	Move Optional Angle			On	On	On	On	On			On			On		On
29	Operational Mode	On	On		On	On	On				On	0n				On
30	Stop				Off	Off	Off									Off

Note: Operational Mode = On, This means that the Input is "On" only when a component passes by the Fibre Optic Sensor.
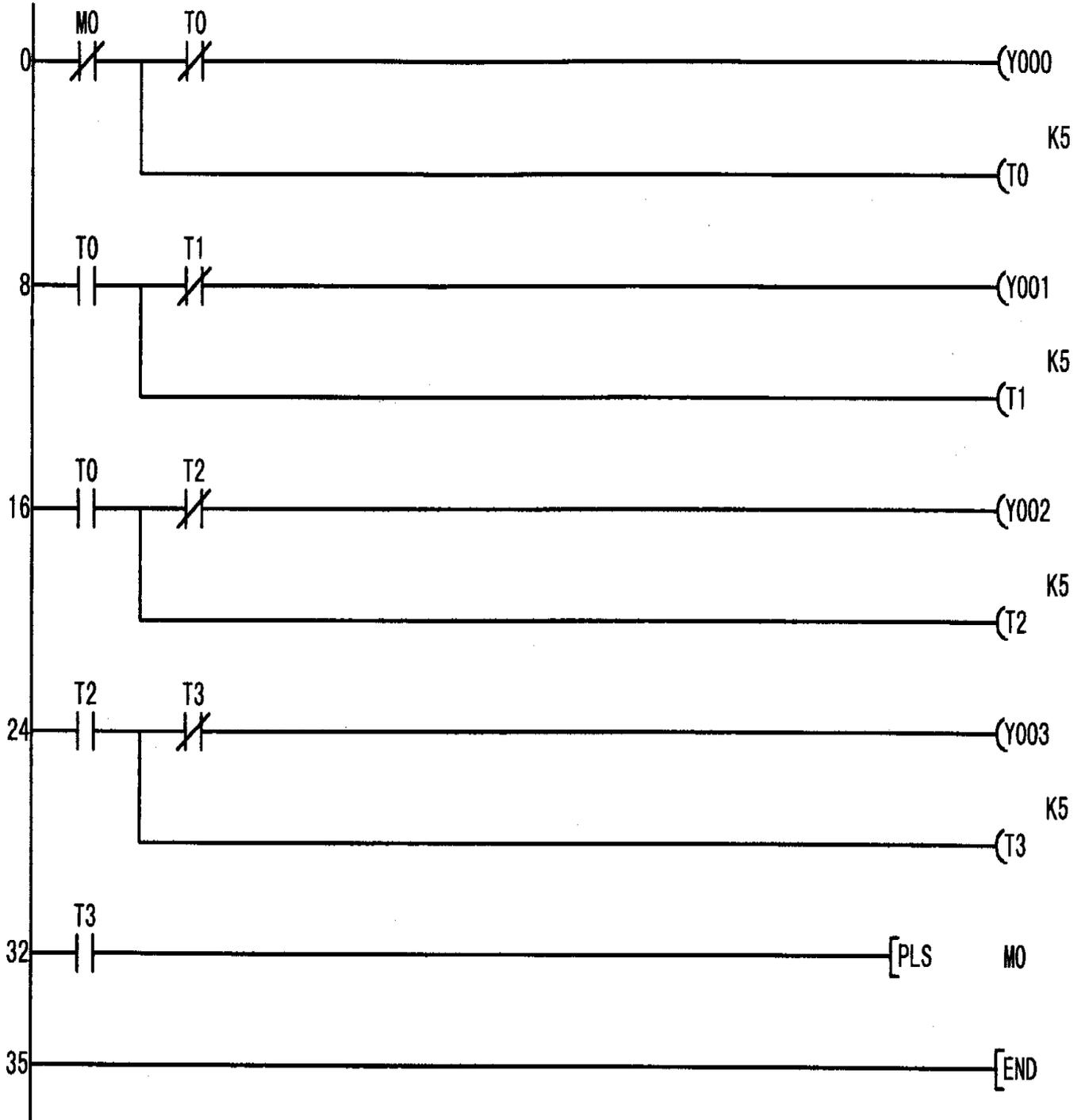
PLC I/O List For Adaptive Vibratory Bowl Feeder
Martin Maher AMT LAB

Wiper Blade Tool
PLC Output Conditions during a Demonstration

Step	Description	Y0	Y1	Y2	Y3	Y7	Y10	Y12	Y13	Y14	Y17
0	Start up							On		On	
1	Operational Mode						On	On		On	On
2	Exp 1 (Angle 1) (Height 0)							On		On	
3	Stop Do Calculations					On		On		On	
4	Move New Height	On	On	On	On	On		On	On		
5	Operational Mode						On	On		On	On
6	Exp 2 (Angle 1) (Height 1)							On		On	
7	Stop Do Calculations							On		On	
8	Move New Height	On	On	On	On	On		On	On		
9	Operational Mode						On	On		On	On
10	Exp 3 (Angle 1) (Height 2)							On		On	
11	Stop Do Calculations					On		On		On	
12	Move Back (Height 0)	On	On	On	On	On		On	On		
13	Move Blade (Angle 2)	On	On	On	On	On			On	On	
14	Operational Mode						On	On		On	On
15	Exp 4 (Angle 2) (Height 0)							On		On	
16	Stop Do Calculations					On		On		On	
17	Move (Angle 2) (Height 1)	On	On	On	On	On		On	On		
18	Operational Mode						On	On		On	On
19	Exp 5 (Angle 2) (Height 1)							On		On	
20	Stop Do Calculations					On		On		On	
21	Move (Angle 2) (Height 2)	On	On	On	On	On		On	On		
22	Operational Mode						On	On		On	On
23	Exp 6 (Angle 2) (Height 2)							On		On	
24	Stop Do Calculations					On		On		On	
25	Move Zero Height	On	On	On	On	On		On	On		
26	Move Zero Angle	On	On	On	On	On			On	On	
27	Move Optional Height	On	On	On	On	On		On	On		
28	Move Optional Angle	On	On	On	On	On			On	On	
29	Operational Mode						On	On		On	On
30	Stop							On		On	

Note: "On", This means that the Output is "On" for a short period of time.

```
*********************************************
**** One Phase Excitation "CLOCKWISE ROTATION"****
*********************************************
```



```
        MO      TO
  0 ────┤/├─────┤/├──────────────────────────────(Y000)

                                                      K5
        └───────────────────────────────────────(T0)

        TO      T1
  8 ────┤ ├─────┤/├──────────────────────────────(Y001)

                                                      K5
        └───────────────────────────────────────(T1)

        TO      T2
 16 ────┤ ├─────┤/├──────────────────────────────(Y002)

                                                      K5
        └───────────────────────────────────────(T2)

        T2      T3
 24 ────┤ ├─────┤/├──────────────────────────────(Y003)

                                                      K5
        └───────────────────────────────────────(T3)

        T3
 32 ────┤ ├──────────────────────────────────────[PLS   MO]

 35 ──────────────────────────────────────────────[END]
```

****
********* **One Phase Excitation, Clockwise Rotation, Step Angle 1.8^0** ********
****

****
 Step 0
****
Start Rotation of the Stepping Motor (Pulse Output (Y0)):

If the Marker (M0) and the Sequence Control Timer (T0) are off, the Output (Y0) goes on

and the Sequence Control Timer (T0) begins timing out. When it has fully timed out after

.5 of a second, the output (Y0) will switch off.

Note: The Output (Y0) represents the first 24Vdc pulse that is sent to the Stepping Motor

and will be used to obtain its first rotational position.

****
 Step 8
****
 Rotating the Stepping Motor (Pulse Output (Y1)):

If the Sequence Control Timer (T0) comes on while the Sequence Control Timer (T1) is

off, the Output (Y1) goes on and the Sequence Control Timer (T1) begins timing out.

When it has fully timed out after .5 of a second, the output (Y1) will switch off.

Note: The Output (Y1) represents a second 24Vdc pulse that is sent to the Stepping Motor

and will be used to obtain its second rotational position.

****
 Step 16
****
Rotating the Stepping Motor (Pulse Output (Y2)):

If the Sequence Control Timer (T1) comes on while the Sequence Control Timer (T2) is

off, the Output (Y2) goes on and the Sequence Control Timer (T2) begins timing out.

When it has fully timed out after .5 of a second, the output (Y2) will switch off.

Note: The Output (Y2) represents the third 24Vdc pulse that is sent to the Stepping Motor

and will be used to obtain its third rotational position.

```
*********
```
Step 24
```
*********
```
<u>Rotating the Stepping Motor (Pulse Output (Y3)):</u>

If the Sequence Control Timer (T2) comes on while the Sequence Control Timer (T3) is

off, the Output (Y3) goes on and the Sequence Control Timer (T3) begins timing out.

When it has fully timed out after .5 of a second, the output (Y3) will switch off.

Note: The Output (Y3) represents the fourth 24Vdc pulse that is sent to the Stepping

Motor and will be used to obtain its fourth rotational position.

```
*********
```
Step 32
```
*********
```
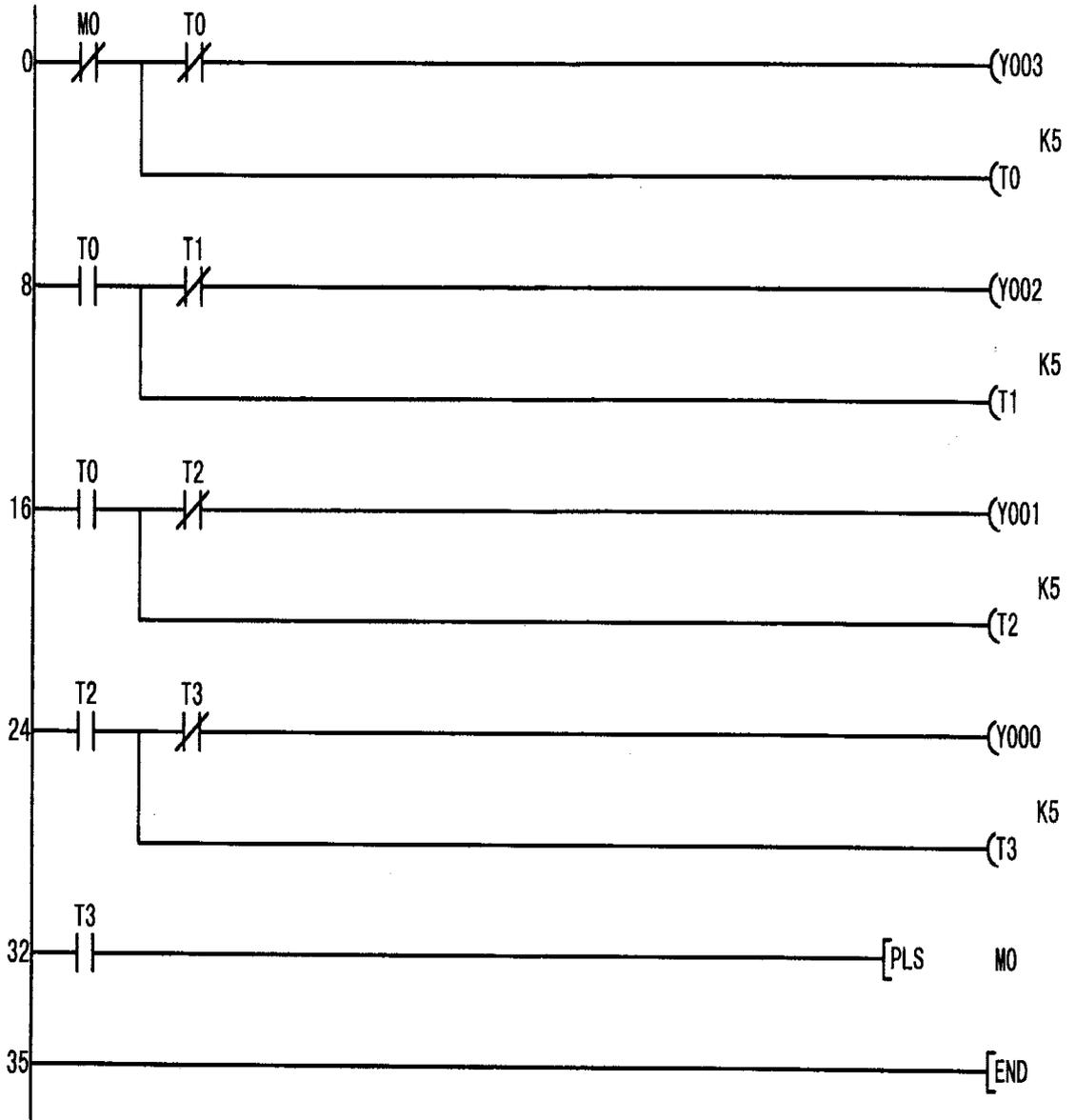**<u>Continuously Repeating the Outputs for Clockwise Rotation:</u>**

When the Sequence Control Timer (T3) comes on, the Marker (M0) will be pulsed

momentarily.

Note: When the Marker (M0) is pulsed the cycle begins again from "Step 0" above,

which will result in a continuous Clockwise Rotation of the Stepping Motor.

```
*********
```
Step 35
```
*********
```

End Program

```
*************************************************
** One Phase Excitation "ANTICLOCKWISE ROTATION***
*************************************************
        MO     TO
 0 ─────┤/├────┤/├──────────────────────────────────(Y003
              │
              │                                      K5
              └──────────────────────────────────────(TO

        TO     T1
 8 ─────┤ ├────┤/├──────────────────────────────────(Y002
              │
              │                                      K5
              └──────────────────────────────────────(T1

        TO     T2
16 ─────┤ ├────┤/├──────────────────────────────────(Y001
              │
              │                                      K5
              └──────────────────────────────────────(T2

        T2     T3
24 ─────┤ ├────┤/├──────────────────────────────────(Y000
              │
              │                                      K5
              └──────────────────────────────────────(T3

        T3
32 ─────┤ ├─────────────────────────────────────[PLS   MO

35 ─────────────────────────────────────────────[END
```

****
****** **One Phase Excitation, Anticlockwise Rotation, Step Angle (1.8^{0})** *******
****

****
 Step 0
****

Start Rotation of the Stepping Motor (Pulse Output (Y3)):

If the Marker (M0) and the Sequence Control Timer (T0) are off, the Output (Y3) goes on

and the Sequence Control Timer (T0) begins timing out. When it has fully timed out after

.5 of a second, the output (Y3) will switch off.

Note: The Output (Y3) represents the first 24Vdc pulse that is sent to the Stepping Motor

and will be used to obtain its first rotational position.

****
 Step 8
****

Rotating the Stepping Motor (Pulse Output (Y2):

If the Sequence Control Timer (T0) comes on while the Sequence Control Timer (T1) is

off, the Output (Y2) goes on and the Sequence Control Timer (T1) begins timing out.

When it has fully timed out after .5 of a second, the output (Y2) will switch off.

Note: The Output (Y2) represents the second 24Vdc pulse that is sent to the Stepping

Motor and will be used to obtain its second rotational position.

****
 Step 16
****

Rotating the Stepping Motor (Pulse Output (Y1):

If the Sequence Control Timer (T1) comes on while the Sequence Control Timer (T2) is

off, the Output (Y1) goes on and the Sequence Control Timer (T2) begins timing out.

When it has fully timed out after .5 of a second, the output (Y1) will switch off.

Note: The Output (Y1) represents the third 24Vdc pulse that is sent to the Stepping Motor

and will be used to obtain its third rotational position.

****
  Step 24
****

<u>Rotating the Stepping Motor (Pulse Output (Y0):</u>

If the Sequence Control Timer (T2) comes on while the Sequence Control Timer (T3) is

off, the Output (Y0) goes on and the Sequence Control Timer (T3) begins timing out.

When it has fully timed out after .5 of a second, the output (Y0) will switch off.

Note: The Output (Y0) represents the fourth 24Vdc pulse that is sent to the Stepping

Motor and will be used to obtain its fourth rotational position.

****
  Step 32
****

<u>Continuously Repeating the Outputs for Anticlockwise Rotation:</u>

When the Sequence Control Timer (T3) comes on, the Marker (M0) will be pulsed

momentarily.

Note: When the Marker (M0) is pulsed, the cycle begins again from "Step 0" above,

which will result in a continuous Anticlockwise Rotation of the Stepping Motor.

****
  Step 35
****

End Program

```
****************************************************
********* Two Phase "CLOCKWISE ROTATION"*********
****************************************************
          M0        T0
  0 ------|/|-------|/|-----------------------------------( M1 )

                                                              K5
          |---------------------------------------------( T0 )

          T0        T1
  8 ------| |-------|/|-----------------------------------( M2 )

                                                              K5
          |---------------------------------------------( T1 )

          T1        T2
 16 ------| |-------|/|-----------------------------------( M3 )

                                                              K5
          |---------------------------------------------( T2 )

          T2        T3
 24 ------| |-------|/|-----------------------------------( M4 )

                                                              K5
          |---------------------------------------------( T3 )

          T3
 32 ------| |-------------------------------------[ PLS  M0 ]

          M1
 35 ------| |---------------------------------------------( M7 )

          |---------------------------------------------( M11 )

          M2
 38 ------| |---------------------------------------------( M8 )

          |---------------------------------------------( M9 )

          M3
 41 ------| |---------------------------------------------( M5 )

          |---------------------------------------------( M10 )

          M4
 44 ------| |---------------------------------------------( M6 )

          |---------------------------------------------( M12 )
```
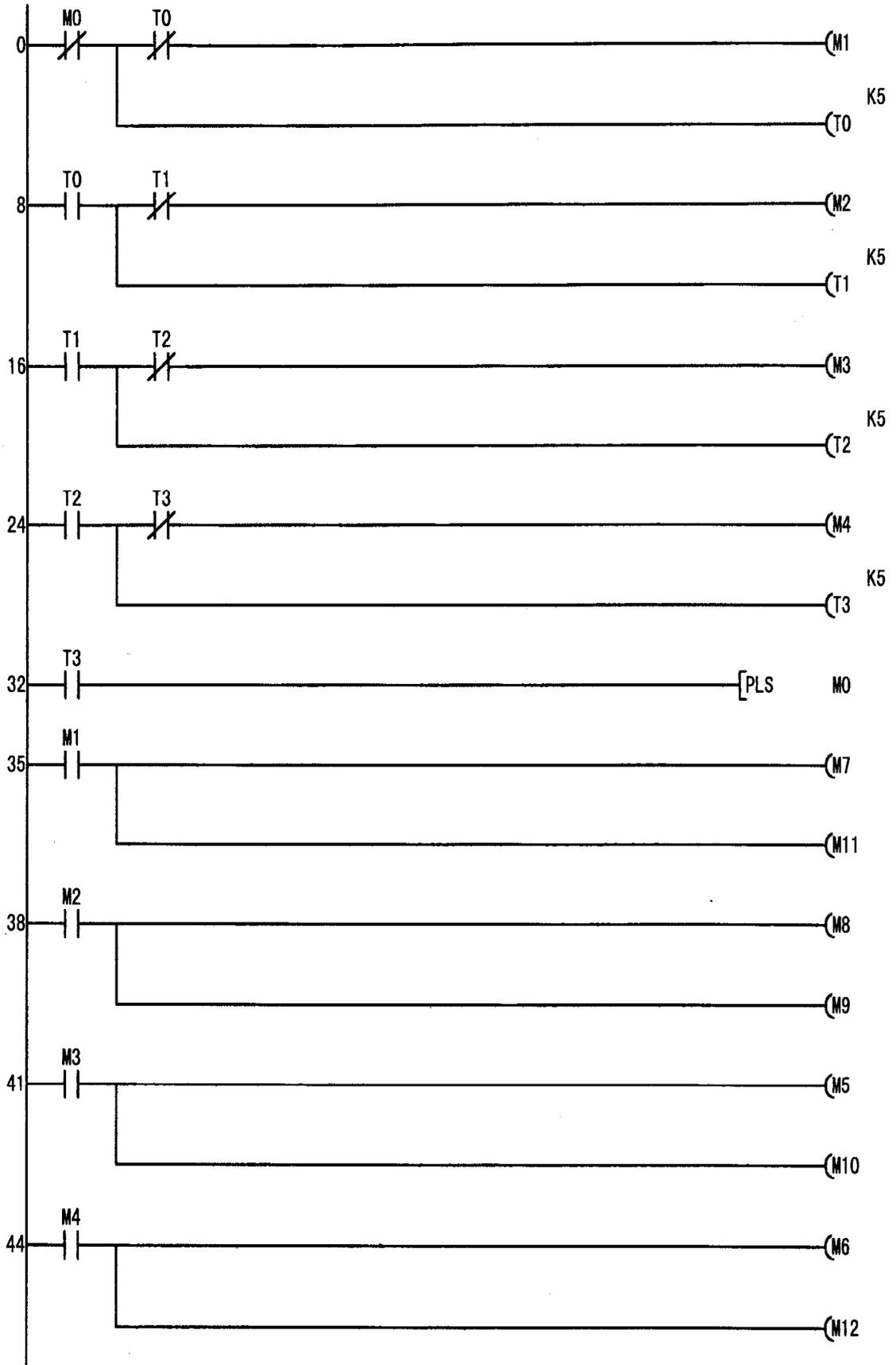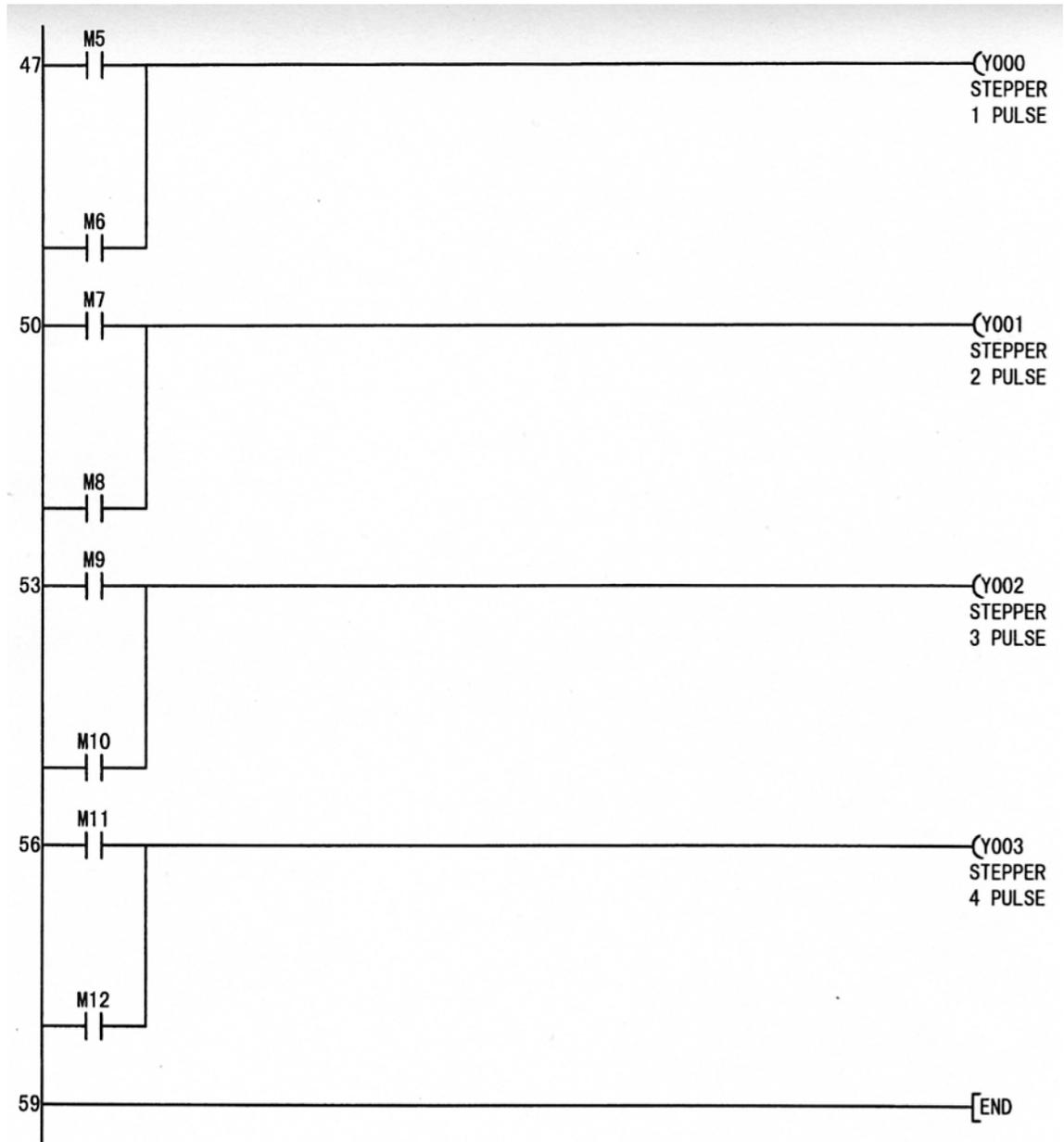
47 — M5 ————————————————————————— (Y000
                                                     STEPPER
                                                     1 PULSE

       — M6 —

50 — M7 ————————————————————————— (Y001
                                                     STEPPER
                                                     2 PULSE

       — M8 —

53 — M9 ————————————————————————— (Y002
                                                     STEPPER
                                                     3 PULSE

       — M10 —

56 — M11 ———————————————————————— (Y003
                                                     STEPPER
                                                     4 PULSE

       — M12 —

59 ——————————————————————————————— [END

```
*********************************************************************
********* Two Phase Excitation, Clockwise Rotation, Step Angle 1.8⁰ *********
*********************************************************************
```

****
 Step 0
****

<u>**Set Marker (M1):**</u>

If the Marker (M0) and the Sequence Control Timer (T0) are off, the Marker (M1) goes

on and the Sequence Control Timer (T0) begins timing out. When it has fully timed out

after .5 of a second, the Marker (M1) will be reset.

Note: The Marker (M1) will be used to control two Markers (M7) and (M11), these

Markers control the Outputs (Y1) and (Y3) simultaneously.

****
 Step 8
****

<u>**Set Marker (M2):**</u>

If the Sequence Control Timer (T0) comes on while the Sequence Control Timer (T1) is

off, the Marker (M2) goes on and the Sequence Control Timer (T1) begins timing out.

When it has fully timed out after .5 of a second, the Marker (M2) will be reset.

Note: The Marker (M2) will be used to control two Markers (M8) and (M9), these

Markers control the Outputs (Y1) and (Y2) simultaneously.

****
 Step 16
****

<u>**Set Marker (M3):**</u>

If the Sequence Control Timer (T1) comes on while the Sequence Control Timer (T2) is

off, the Marker (M3) goes on and the Sequence Control Timer (T2) begins timing out.

When it has fully timed out after .5 of a second, the Marker (M3) will be reset.

Note: The Marker (M3) will be used to control two Markers (M5) and (M10), these

Markers control the Outputs (Y0) and (Y2) simultaneously.

```
*********
  Step 24
*********
```
Set Marker (M4):

If the Sequence Control Timer (T2) comes on while the Sequence Control Timer (T3) is

off, the Marker (M4) goes on and the Sequence Control Timer (T3) begins timing out.

When it has fully timed out after .5 of a second, the Marker (M4) will be reset.

Note: The Marker (M4) will be used to control two Markers (M6) and (M12), these

Markers control the Outputs (Y0) and (Y3) simultaneously.

```
*********
  Step 32
*********
```
Continuous rotation of the Stepping Motor:

When the Sequence Control Timer (T3) is on the Marker (M0) will be pulsed.

Note: The Marker (M0) will start the cycle again from "Step 0" above, which will result

in a continuous Clockwise Rotation of the Stepping Motor.

```
*********
  Step 35
*********
```
Set Markers (M7) & (M11):

When Marker (M1) goes on, Markers (M7) and (M11) will be set.

```
 *********
  Step 38
*********
```
Set Markers (M8) & (M9):

When Marker (M2) goes on, Markers (M8) and (M9) will be set.

```
*********
  Step 41
*********
```
Set Markers (M5) & (M10):

When Marker (M3) goes on, Markers (M5) and (M10) will be set.

****
 Step 44
****
Set Markers (M6) & (M12):

When Marker (M4) goes on, Markers (M6) and (M12) will be set.

****
 Step 47
****
Set the Output (Y0):

If the Marker (M5) or the Marker (M6) comes on, the Output (Y0) will come on.

****
 Step 50
****
Set the Output (Y1):

If the Marker (M7) or the Marker (M8) comes on, the Output (Y1) will come on.

****
 Step 53
****
Set the Output (Y2):

If the Marker (M9) or the Marker (M10) comes on, the Output (Y2) will come on.

****
 Step 56
****
Set the Output (Y3):

If the Marker (M11) or the Marker (M12) comes on, the Output (Y3) will come on.

****
 Step 59
****
End Program.

```
* ***************************************************
* ****** Two Phase, "ANTICLOCKWISE ROTATION"*******
* ***************************************************
          M0      T0
    0 ────┤/├─────┤/├──────────────────────────────────(M4

                                                             K5
          ├──────────────────────────────────────(T0

          T0      T1
    8 ────┤ ├─────┤/├──────────────────────────────────(M3

                                                             K5
          ├──────────────────────────────────────(T1

          T1      T2
   16 ────┤ ├─────┤/├──────────────────────────────────(M2

                                                             K5
          ├──────────────────────────────────────(T2

          T2      T3
   24 ────┤ ├─────┤/├──────────────────────────────────(M1

                                                             K5
          ├──────────────────────────────────────(T3

          T3
   32 ────┤ ├────────────────────────────────[PLS    M0

          M1
   35 ────┤ ├──────────────────────────────────────(M7

          ├──────────────────────────────────────(M11

          M2
   38 ────┤ ├──────────────────────────────────────(M8

          ├──────────────────────────────────────(M9

          M3
   41 ────┤ ├──────────────────────────────────────(M5

          ├──────────────────────────────────────(M10

          M4
   44 ────┤ ├──────────────────────────────────────(M6

          ├──────────────────────────────────────(M12

          M5
   47 ────┤ ├──┬───────────────────────────────────(Y000
          M6    │
          ┤ ├──┘
```

200

```
**********************************************************************
******** Two Phase Excitation, Anticlockwise Rotation, Step Angle 1.8⁰ *******
**********************************************************************
```
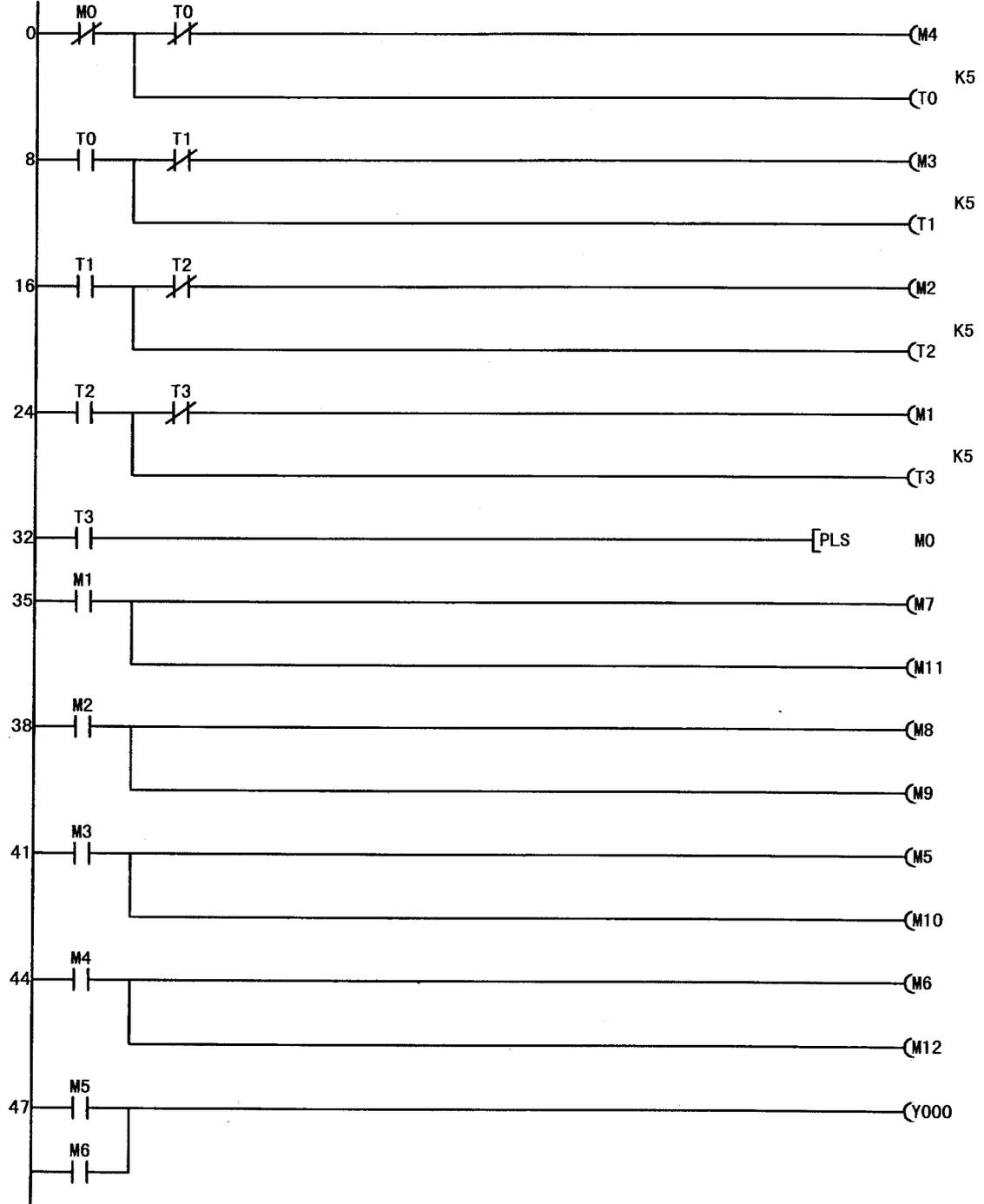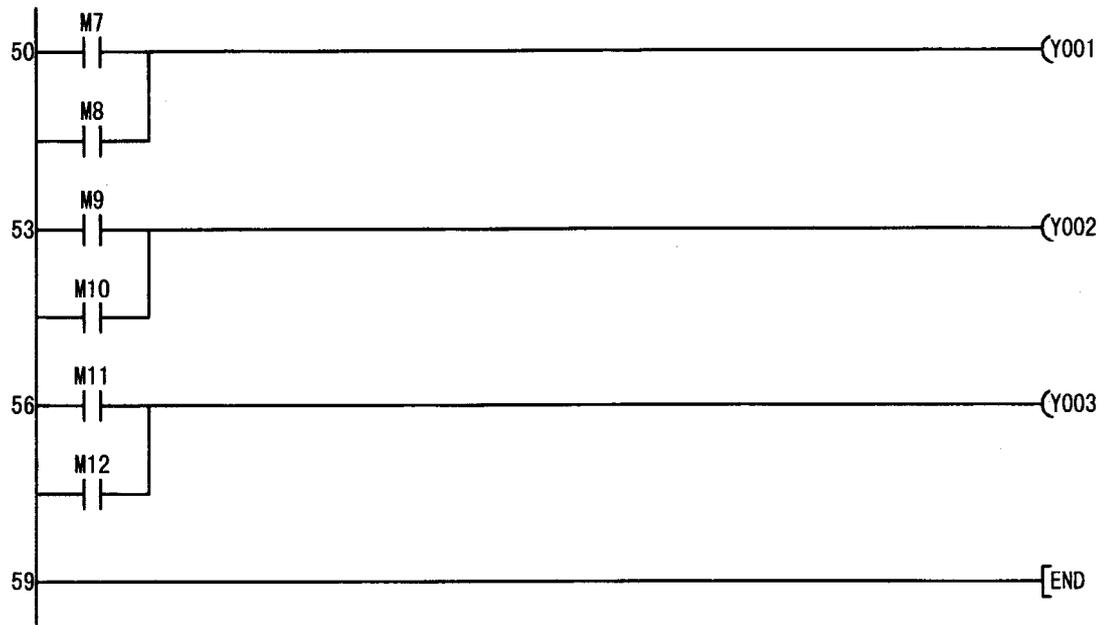
****
 Step 0
****

Set Marker (M4):

If the Marker (M0) is off along with the Sequence Control Timer (T0), the Marker (M4) goes on and the Sequence Control Timer (T0) begins timing out. When it has fully timed out after .5 of a second, the Marker (M4) will be reset.

Note: The Marker (M4) will be used to control two Markers (M6) and (M12), these Markers control the Outputs (Y0) and (Y3) simultaneously.

****
 Step 8
****

Set Marker (M3):

If the Sequence Control Timer (T0) comes on while the Sequence Control Timer (T1) is off, the Marker (M3) goes on and the Sequence Control Timer (T1) begins timing out. When it has fully timed out after .5 of a second, the Marker (M3) will be reset.

Note: The Marker (M3) will be used to control two Markers (M5) and (M10), these Markers control the Outputs (Y0) and (Y2) simultaneously.

****
 Step 16
****

Set Marker (M2):

If the Sequence Control Timer (T1) comes on while the Sequence Control Timer (T2) is off, the Marker (M2) goes on and the Sequence Control Timer (T2) begins timing out. When it has fully timed out after .5 of a second, the Marker (M2) will be reset.

Note: The Marker (M2) will be used to control two Markers (M8) and (M9), these Markers control the Outputs (Y1) and (Y2) simultaneously.

****
Step 24
****
<u>**Set Marker (M1):**</u>

If the Sequence Control Timer (T2) comes on while the Sequence Control Timer (T3) is

off, the Marker (M1) goes on and the Sequence Control Timer (T3) begins timing out.

When it has fully timed out after .5 of a second, the Marker (M1) will be reset.

Note: The Marker (M1) will be used to control two Markers (M7) and (M11), these

Markers control the Outputs (Y1) and (Y3) simultaneously.

****
 Step 32
****
<u>**Set Marker (M1):**</u>

When the Sequence Control Timer (T3) comes on the Marker (M0) will be pulsed.

Note: When the Marker (M0) is pulsed cycle begins again from "Step 0" above, which

will result in a continuous Anticlockwise Rotation of the Stepping Motor.

****
Step 35
****
<u>**Set Markers (M7) & (M11):**</u>

When Marker (M1) goes on, Markers (M7) and (M11) will be set.

 ****
Step 38
****
<u>**Set Markers (M7) & (M11):**</u>

When Marker (M2) goes on, Markers (M8) and (M9) will be set.

****
 Step 41
****
<u>**Set Markers (M5) & (M10):**</u>

When Marker (M3) goes on, Markers (M5) and (M10) will be set.

****
 Step 44
****
Set Markers (M6) & (M12):

When Marker (M4) goes on, Markers (M6) and (M12) will be set.

****
 Step 47
****
Set the Output (Y0):

If the Marker (M5) or the Marker (M6) comes on, the Output (Y0) will come on.

****
 Step 50
****
Set the Output (Y1):

If the Marker (M7) or the Marker (M8) comes on, the Output (Y1) will come on.

****
 Step 53
****
Set the Output (Y2):

If the Marker (M9) or the Marker (M10) comes on, the Output (Y2) will come on.

****
 Step 56
****
Set the Output (Y3):

If the Marker (M11) or the Marker (M12) comes on, the Output (Y3) will come on.

****
 Step 59
****
End Program.

```
**************************************************
******* Half Stepping, "CLOCKWISE ROTATION"*******
**************************************************
```



```
        MO      T0
 0 ─────┤/├─────┤/├──────────────────────────────────(M1

                                                       K5
        └────────────────────────────────────────────(T0

        T0      T1
 8 ─────┤ ├─────┤/├──────────────────────────────────(M2

                                                       K5
        └────────────────────────────────────────────(T1

        T1      T2
16 ─────┤ ├─────┤/├──────────────────────────────────(M3

                                                       K5
        └────────────────────────────────────────────(T2

        T2      T3
24 ─────┤ ├─────┤/├──────────────────────────────────(M4

                                                       K5
        └────────────────────────────────────────────(T3

        T3
32 ─────┤ ├──────────────────────────────────[PLS    MO

        M1     M18     M6      M7      M8     M10     M11
35 ─────┤ ├────┤/├────┤/├────┤/├────┤/├────┤/├────┤/├──(Y000

        M2            M5      M6     M11     M12     M13
        ├ ├──────────┤/├────┤/├────┤/├────┤/├────┤/├──(Y001

        M3            M8     M10     M11     M12     M13
        ├ ├──────────┤/├────┤/├────┤/├────┤/├────┤/├──(Y002

        M4            M5      M6      M7      M8     M13
        ├ ├──────────┤/├────┤/├────┤/├────┤/├────┤/├──(Y003

        M1     M9
68 ─────┤ ├────┤/├──────────────────────────────────(M5

                                                  [RST    M6

        M17    M9
        ├/├────┤ ├───────────────────────────────────(M10

                                                  [RST    M11
```
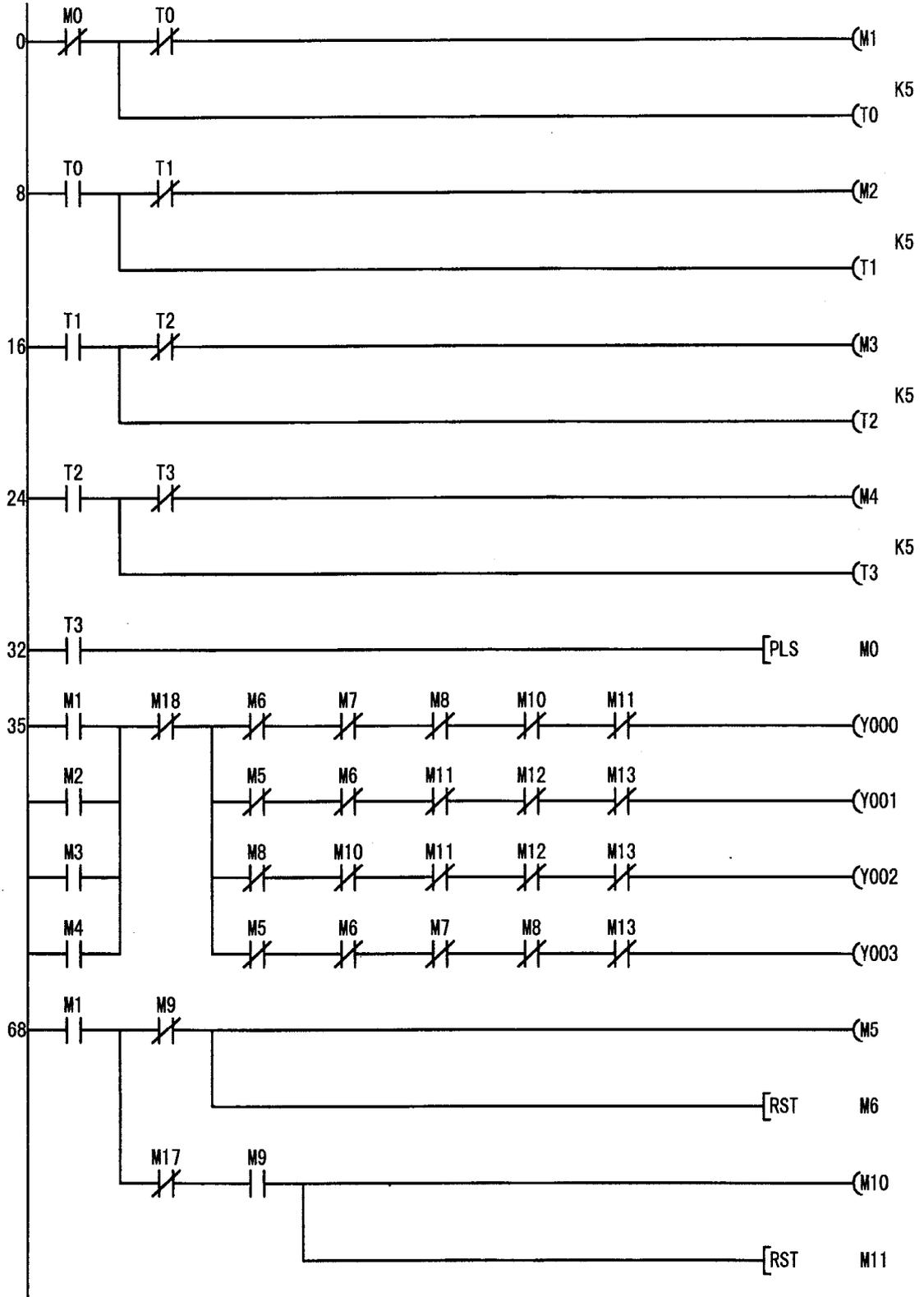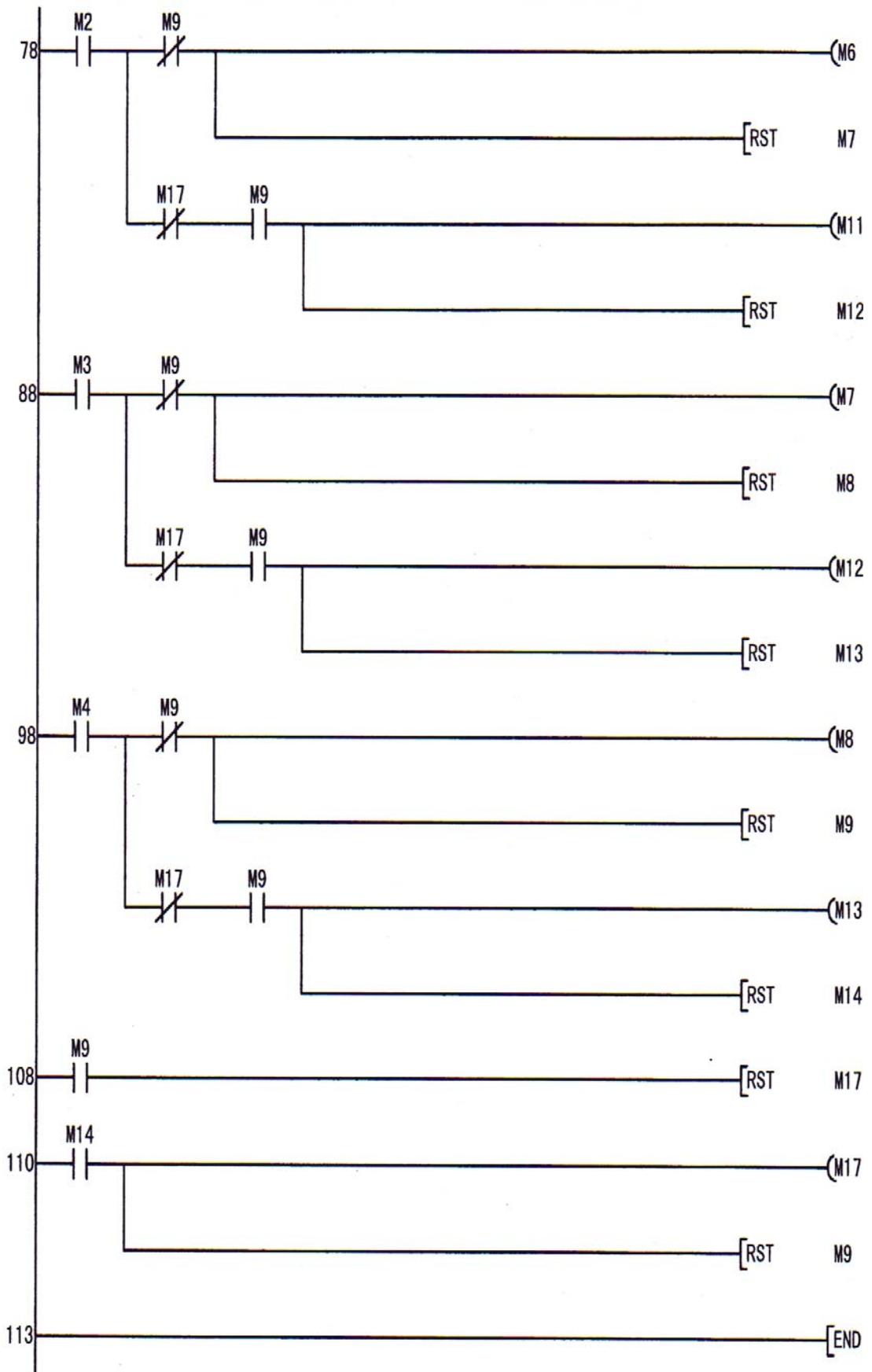
****
********** **Half-Step Excitation, Clockwise Rotation, Step Angle .9^0** **********
****

****
 Step 0
****
Set Marker (M1):

If the Marker (M0) and the Sequence Control Timer (T0) is off, the Marker (M1) goes on

and the Sequence Control Timer (T0) begins timing out. When it has fully timed out after

.5 of a second, the Marker (M1) will be reset.

Note: The Marker (M1) will set and reset markers, which will be used to control the

Stepping Motor Outputs.

****
 Step 8
****
Set Marker (M2):

If the Sequence Control Timer (T0) comes on while the Sequence Control Timer (T1) is

off, the Marker (M2) goes on and the Sequence Control Timer (T1) begins timing out.

When it has fully timed out after .5 of a second, the Marker (M2) will be reset.

Note: The Marker (M2) will set and reset markers, which will be used to control the

Stepping Motor Outputs.

****
 Step 16
****
Set Marker (M2):

If the Sequence Control Timer (T1) comes on while the Sequence Control Timer (T2) is

off, the Marker (M3) goes on and the Sequence Control Timer (T2) begins timed out.

When it has fully timed out after .5 of a second, the Marker (M3) will be reset.

Note: The Marker (M3) will set and reset markers, which will be used to control the

Stepping Motor Outputs.

****
   Step 24
****
<u>**Set Marker (M2):**</u>

If the Sequence Control Timer (T2) comes on while the Sequence Control Timer (T3) is

off, the Marker (M4) goes on and the Sequence Control Timer (T3) begins timing out.

When it has fully timed out after .5 of a second, the Marker (M4) will be reset.

Note: The Marker (M4) will set and reset markers, which will be used to control the

Stepping Motor Outputs.

****
   Step 32
****
<u>**Repeating the Stepping Motor Cycle:**</u>

When the Sequence Control Timer (T3) comes on the Marker (M0) is pulsed.

Note: When the Marker (M0) is pulsed the Stepping Motor cycle begins again from "Step

0" above, which will result in a continuous clockwise Rotation of the Stepping Motor.

****
   Step 35
****
<u>**Controlling the Stepping Motor Outputs:**</u>

If any one of the Markers (M1), (M2), (M3) or (M4) are on while the Marker (M18) is off

it is possible to obtain simultaneous or independent control of the Outputs (Y0), (Y1),

(Y2) or (Y3).

Note: This is achieved by controlling the operation of all the other markers on this line

independently of one another.

****

Step 68

****

Sequence One:

If Marker (M1) is on while Marker (M9) is off, the Marker (M5) is turned on and the

Marker (M6) will be reset.

Note: This will result in the Outputs (Y0) and (Y2) switching on simultaneously.

Sequence Two:

If Marker (M1) is on while Marker (M17) is off and Marker (M9) is on, the Marker

(M10) is turned on and the Marker (M11) will be reset.

Note: This will result in the Output (Y1) and (Y3) switching on simultaneously.

****

Step 78

****

Sequence One:

If Marker (M2) is on while Marker (M9) is off, the Marker (M6) is turned on and the

Marker (M7) will be reset.

Note: The Output (Y2) will be switching on only.

Sequence Two:

If Marker (M2) is on while Marker (M17) is off and Marker (M9) is on, the Marker

(M11) is turned on and the Marker (M12) will be reset.

Note: The Output (Y3) will be switching on only.

****

Step 88

****

Sequence One:

If Marker (M3) is on while Marker (M9) is off, the Marker (M7) is turned on and the

Marker (M8) will be reset.

Note: This will result in the Outputs (Y1) and (Y2) switching on simultaneously.

 Sequence Two:

If Marker (M3) is on while Marker (M17) is off and Marker (M9) is on, the Marker

(M12) is turned on and the Marker (M13) will be reset.

Note: This will result in the Output (Y0) and (Y3) switching on simultaneously.

****
 Step 98
****
Sequence One:

If Marker (M4) is on while Marker (M9) is off, the Markers (M8) and (M9) will be

switched on.

Note: The Output (Y1) will be switching on only.

Sequence Two:

If Marker (M4) is on while Marker (M17) is off and Marker (M9) is on, the Marker

(M13) is turned on and the Marker (M14) will be reset.

Note: The Output (Y0) will be switching on only.

****
 Step 108
****
Controlling the Sequence Two Outputs only:

When Marker (M9) switches on the Marker (M17) will be reset.

Note: If Marker (M17) has been reset, the Sequence Two outputs are operated only.

****
 Step 110
****
Controlling the Sequence One Outputs only:

When Marker (M14) switches on the Marker (M17) will be set and the Marker (M9) will

be reset. Note: In this case Sequence one outputs are being operated only.

End Program.

```
* ************************************************
* **** Wiper Blade, Experiments & Demonstration ****
* ************************************************
```

```
        M76      M11      C4
65  ────┤├──────┤/├──────┤/├──────────────────────────────────(M33
                   │
                   │                                          K26
                   └──────────────────────────────────────────(C4
                          │
                          └─────────────────────────[MOV    C4      C9

        M33      C5       C4
79  ────┤├──────┤/├──────┤├───────────────────────────────────(M34
                          │
                          └─────────────────────────[RST            C9

        X011     M150
85  ────┤├───────┤├────────────────────────────────[PLS            M19

        M19      M9       M150
89  ────┤├──────┤/├──────┤├─────────────────────────[INC            C2

        X003     M150
95  ────┤├───┬───┤├────────────────────────────────[PLS            M21
        X004  │
        ──┤├──┤
        X005  │
        ──┤├──┘

        M21      M9       M150
101 ────┤├──────┤/├──────┤├───────────────────────[INC            C8
                                  │
                                  └───────────────[MOV    C8      C11

        M19      M9                                        K1000
112 ──┬──┤├───┬──┤/├───────────────────────────────────────(C10
     │ M21   │
     └──┤├───┘

        X011     M150
118 ────┤├───────┤├────────────────────────────────[PLF            M22
        X003     M150
        ──┤├──┬──┤├──┬─────────────────────────────[PLS            M23
        X004  │      │
        ──┤├──┤      │
        X005  │      │
        ──┤├──┘

        M22      M9       M150
129 ────┤├──────┤/├──────┤├─────────────────────────[SET            M24
```

```
190  ─┤ ├─────────────────────────────────────────────[RST    M9
                                                        [PLS    M25
                                                        [RST    M77

        M9
195  ─┤/├─────────────────────────────────────────────[RST    M152

        C10
197  ─┤ ├─────────────────────────────────────────────[PLS    M80
        X022
       ─┤ ├─

        M80
201  ─┤ ├──────────────────────────────────[MOV    C2     D22
                                            [MOV    C11    D23
                                            [MOV    C5     D5
                                            [MOV    C6     D6
                                            [MOV    C10    D25
                                                        [PLS    M120

        M120
229  ─┤ ├──────────────────────────────[MUL    D6    K20    D10
                                                        [PLS    M130

        M130
239  ─┤ ├──────────────────────────────[SUB    D22   D10    D11
                                                        [PLS    M131

        M131
249  ─┤ ├──────────────────────────────[MUL    D11   K100   D9
                                                        [PLS    M134

        M134
259  ─┤ ├──────────────────────────────[DIV    D9    D25    D12
                                                        [PLS    M132
```

214

```
347  ──M100──┤ ├──┤M106├/┤──┤M108├/┤──────────────────────[RST    M1

351  ──X001──┤ ├──────────────────────────────────────────[SET    M2

353  ──M2────┤ ├──┬───────────────────────────────────────(Y014

     ──M105──┤ ├──┤
     ──M109──┤ ├──┘

357  ──M101──┤ ├──┤M105├/┤──┤M109├/┤──────────────────────[RST    M2

361  ──M31───┤ ├──┤M11├┤ ├──┬──────────────────────────────[PLS    M3

     ──M23───┤ ├─────────┤M23├/┤──────────────[MOV    K6     D13

                          ┤M31├/┤──────────────[MOV    K102   D13

380  ──M32───┤ ├──┬────────────────────────────────────────[PLS    M4

             ├──────────────────────────────────[MOV    K90    D17

             └────────────────────────────────────[RST    M32

389  ──M33───┤ ├──┬────────────────────────────────────────[PLS    M5

     ──M24───┤ ├─────────┤M24├/┤──────────────[MOV    K1     D7

                          ┤M33├/┤──────────────[MOV    K2     D7

407  ──M34───┤ ├──┬────────────────────────────────────────[PLS    M6

             └──────────────────────────────────[MOV    K7     D19

415  ──M3────┤ ├─────────────────────────────[ADD    D0     K2     D0

423  ──M4────┤ ├─────────────────────────────[ADD    D1     K2     D1

431  ──M5────┤ ├─────────────────────────────[ADD    D2     K2     D2
```

```
        M6
439 ├──┤├──────────────────────────────────────[ADD    D3      K2      D3

        M3
447 ├──┤├──────────────────────────────────────[CMP    D0      K1      M7

                    M7
           ├──┤├──────────────────────────────────────[SET    M10

        M4
457 ├──┤├──────────────────────────────────────[CMP    D1      K1      M37

                    M37
           ├──┤├──────────────────────────────────────[SET    M45

        M5
467 ├──┤├──────────────────────────────────────[CMP    D2      K1      M17

                    M17
           ├──┤├──────────────────────────────────────[SET    M20

        M6
477 ├──┤├──────────────────────────────────────[CMP    D3      K1      M48

                    M48
           ├──┤├──────────────────────────────────────[SET    M40

        M20
487 ├──┤├──────────────────────────────────────[ZRST   D0      D1

                                                                        K2
           ├──────────────────────────────────────────────────────────(T1

           ├──────────────────────────────────────[RST    D3

        M45
499 ├──┤├──────────────────────────────────────[ZRST   D2      D3

                                                                        K2
           ├──────────────────────────────────────────────────────────(T4

           ├──────────────────────────────────────[RST    D0

           ├──────────────────────────────────────[SET    M101

        M40
512 ├──┤├──────────────────────────────────────[ZRST   D0      D2

                                                                        K2
           ├──────────────────────────────────────────────────────────(T5

           ├──────────────────────────────────────[RST    D4
```

```
        M10
524  ─┤ ├──┬──────────────────────────────────────[ZRST    D1      D3
          │                                                          K2
          ├──────────────────────────────────────────────────────(T3
          │
          └─────────────────────────────────────────[SET    M101

        M20    X002     M63
534  ─┤ ├───┤ ├────┬──│/│──────────────────────────[SET    M100
                   │                                                K10
                   └───────────────────────────────────────────(T20

        T20    X002                                                K30
543  ─┤ ├───┤ ├──────────────────────────────────────────────(T21

        T21
548  ─┤ ├──────────────────────────────────────────[RST    M28

        T1
550  ─┤ ├──────────────────────────────────────────[SET    M27

        M40    X002
552  ─┤ ├───┤ ├──────┬─────────────────────────────[SET    M100
                     │                                             K10
                     └──────────────────────────────────────────(T22

        T22    X002                                               K30
558  ─┤ ├───┤ ├──────────────────────────────────────────────(T23

        T23
563  ─┤ ├──────────────────────────────────────────[RST    M108

        T5
565  ─┤ ├──────────────────────────────────────────[SET    M73

        T3
567  ─┤ ├──────────────────────────────────────────[SET    M59

        T4
569  ─┤ ├──────────────────────────────────────────[SET    M61

        M27    M65
571  ─┤ ├──│/│──┬───────────────────────────────────────────(Y013
        M59    M67 │
       ─┤ ├──│/│──┤
        M61    M60 │
       ─┤ ├──│/│──┤
        M73    M47 │
       ─┤ ├──│/│──┘

        M73                                                       K8
583  ─┤ ├──────────────────────────────────────────────────────(T6
```

218

```
         M27                                                        K8
587  ———| |————————————————————————————————————————————————————(T2      )

         M10   X000
591  ———| |———| |————————————————————————————————————————————[SET    M350 ]
          |
         M20
     ———| |———
          |
         M45
     ———| |———
          |
         M40
     ———| |———

         M350
597  ———| |——————————————————————————————————————————————————————(Y007   )

         M68    M69    M58    M75
599  ———|/|———|/|———|/|———|/|————————————————————————————————[RST    M350 ]
```

219

```
        M10      T3      T208    X002    M20     M45     M40                         K50
759 ─┤├──────┤├──────┤├──────┤├──────┤/├──────┤/├──────┤/├────────────────────(T209
        Y001                      │
     ─┤├──────────────────────────┘
   STEP 2


        M45      T4      T214    X002    M10     M20     M40                         K50
770 ─┤├──────┤├──────┤├──────┤├──────┤/├──────┤/├──────┤/├────────────────────(T215
        Y001                      │
     ─┤├──────────────────────────┘
   STEP 2


        M40      T6      T217    X002    M10     M20     M45                         K50
781 ─┤├──────┤├──────┤├──────┤├──────┤/├──────┤/├──────┤/├────────────────────(T218
        Y001                      │
     ─┤├──────────────────────────┘
   STEP 2
```

935 ──┤M10├──┤T3├──┤T210├──┬──┤X002├──┤/M20├──┤/M45├──┤/M40├──────────────────(T211) K50
   ──┤Y003├────────────────┤   ──┤X002├──┤T211├─────────────────────────[PLS M104
   STEP 4

952 ──┤/M107├──┤M45├──┤T4├──┬──┤X002├──┤/M10├──┤/M20├──┤/M40├──────────────(T213) K50
   ──┤Y003├────────────────┤
   STEP 4

963 ──┤M40├──┤T6├──┤T219├──┬──┤X002├──┤/M10├──┤/M20├──┤/M45├──────────────(T220) K50
   ──┤Y003├────────────────┤   ──┤X002├──┤T220├────────────────────────[PLS M110
   STEP 4

980 ──┤C3├──┬──[SET M64
           ├──(T11) K20
           ├──[SET M105
           └──[RST D13

989 ──┤T11├──┬──(T18) K20
            ├──┤/T3├──┤X001├────────────────────────────────[RST M10
            └──[SET M67

999 ──┤T11├──┤T18├──┤/M10├──────────────────────────────────[SET M69

```
           X001    M69
1051 ──────┤├──────┤├────────────────────────────────────────[RST    M8

                         ────────────────────────────────────[RST    M101

                         ────────────────────────────────────[RST    T18

                         ────────────────────────────────────[RST    M69

                         ────────────────────────────────────[RST    M59

                         ────────────────────────────────────[RST    M64

                         ────────────────────────────────────[RST    M67

                         ────────────────────────────────────[RST    T11

                         ────────────────────────────────────[RST    C3

                         ────────────────────────────[ZRST    D0      D4

                         ────────────────────────────────────[RST    M105
```

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```
****************************************************************
**************** Wiper Blade Tool Experiments ****************
****************************************************************
```

```
*********
 Step 0
*********
```

Start the Experiment Cycle:

If Input (X27) is on, the Counter (C10) is off and the Output (Y7) is off, the Marker (M150) will be set. However if the Inputs (X27), (X7) and (X10) are on, the Marker (M150) will also be set. When (X27) comes on the Marker (M26) will be pulsed.

Note: The PLC run switch (X27) will be manually switched on at the beginning of the experiments, the Marker (M150) will then be set and the Marker (M26) will be pulsed. These Markers are used to begin the Experiment Cycle.

```
*********
 Step 12
*********
```

Initialising and Resetting of the Counters and Data Registers:

When the Marker (M26) comes on the Counters (C2) and (C8) are reset to zero.

Note: These counters and Data Registers are reset at the beginning of each Experiment. Counter (C2) counts the number of components that successfully make it past (Pass By) the trap, while the Counter (C8) counts the number of components that are rejected (Fall Off) back into the Vibration Bowl.

```
*********
 Step 19
*********
```

If the Output (Y7) is off while the Marker (M11) is on, the Counters (C2) and (C8) are reset to a value of zero.

Note: The counters can also be reset if the Vibration Bowl Relay goes off (Marking the end of an experiment).

****
 Step 25
****

Resetting the Counter which Registers the Number of Blockages:

If the Output (Y7) is off while the Marker (M11) is on, the Marker (M13) will be pulsed

and the Counter (C6) will be reset to zero. If the Marker (M150) comes on only, the

Marker (M13) will be pulsed and the Counter (C6) will be reset.

Note: The Blockage Counter (C6) registers the number of blockages that occur during

each experiment; this must be reset at start of each experiment.

****
 Step 32
****

Resetting the Experiment Quantity counter:

When the Marker (M13) is pulsed, the Counter (C10) is reset.

Note: The Experiment Quantity Counter (C10) will be reset at the beginning of each

experiment; this allows the PLC program to count the number of components being

experimented with during the experiments.

****
 Step 35
****

Move the Stepping Motor after each experiment, calculate and store the results:

If the Marker (M11) is on while the Counter (C5) is off, the Marker (M15) will be pulsed.

If the Marker (M11) is on while the Counter (C5) is on, the Marker (M77) will be set. The

Marker (M77) will stay on while the (T7) times out. After one second the Marker (M35)

will come on.

Note: The wiper blade must be cleared of all obstructing parts before the Stepping motor

is moved. In this case an Air Blast will be used to clear the obstructing parts. The Air

Blast Marker (M77) will stay on for a period of one second while Timer (T7) times out.

****
  Step 50
****

Move the Stepping Motor Clockwise to change the Height:

When the Marker (M15) is pulsed, the Counter (C5) is incremented by a value of one. If the Marker (M15) is pulsed while the Counter (C5) is off, the Marker (M31) will be set and the value in Counter (C5) will be moved into Data Register (D101^z).

Note: The Marker (M31) will be used to move the Stepping Motor through a control number of steps adjusting the Height of the Wiper Blade. The Counter (C5) will count 26 height adjustments as the experiments are conducted, the angle of the Wiper Blade will not be changed until these experiments are complete. The value stored in Counter (C5) will be stored in Data Register (D101^z).

****
  Step 63
****

Move the Stepping Motor Anticlockwise back to its starting height (Zero Height):

When the Marker (M35) comes on the Marker (M32) will be set.

Note: The Marker (M32) will be used to move the Stepping Motor through a control number of steps in an Anticlockwise rotation, this movement changes the height of the Wiper Blade back to it's original position (Zero Height).

****
  Step 65
****

Change the Angle of the Wiper Blade (Clockwise 7.8^0):

If the Marker (M76) is pulsed while the Marker (M11) is off, a value of 1 will be added to the Counter (C4). This value is then moved into Counter (C9). When the value in Counter (C4) reaches a maximum of 26 the Marker (M33) will be set.

Note: The Marker (M33) will be used to change the Angular position of the Wiper Blade after 26 experiments are completed at the required Angle.

****
Step 79
****
Move the Wiper Blade Anticlockwise back to its starting position (Zero Angle):

If the Counters (C33) and (C4) are on, while the Counter (C5) is off, the Marker (M34) is

set and the Counter (C9) will be reset to zero.

Note: When the experiments are complete the Wiper Blade will be moved back to its

starting position by setting the Marker (M34). This means that some of the counters will

be reset to zero.

****
Step 85
****
Count the number of components which successfully Pass the Wiper Blade Trap:

If Input (X11) is on and Marker (M150) is set, the Marker (M19) will be pulsed.

Note: When a component has successfully passed the Wiper Blade in the correct

orientation the Fibre Optic Sensor (X11) will switch on and off again. This will count the

number of components that pass by the trap in the correct orientation.

****
Step 89
****
Avoiding Conflicting Signals:

If the Markers (M19) and (M150) are on while the Marker (M9) is off, the Counter (C2)

will increment by a value of 1.

Note: The Counter (C2) will be used to count the number of components that successfully

pass the Wiper Blade Trap in the correct orientation. The Blockage Marker (M9) should

be off to prevent any conflicting PLC instructions.

****
Step 95
****

If any one of the Inputs (X3), (X4) or (X5) come on while the Marker (M150) is on the Marker (M21) will be pulsed.

Note: The Fibre Optic Sensors (X3), (X4) and (X5) are used to count the number of components that are rejected by the Wiper Blade Trap i.e. the Fall Off Rate.

****
 Step 101
****

Determine the Rejection Rate at the Wiper Blade:

When Marker (M21) is pulsed while Marker (M150) is on and Marker (M9) is off, the Counter (C8) will incremented by a value of 1. The new value in Counter (C8) will be moved into Counter (C11).

Note: The number of components that are rejected by the Wiper Blade must be counted and stored in order to determine the efficiency of the Wiper Blade for that specific location. The Rejection Rate is stored in Counter (C11).

****
 Step 112
****

<u>To determine when the Experiment Quantity (1000 components) is reached:</u>

If the Marker (M19) or the Marker (M21) is pulsed while the blockage Marker (M9) is off, the Counter (C10) will increment by a value of 1.

Note: Markers (M19) and (M21) are used to count the number of components which "Pass By" and "Fall Off" at the Wiper Blade location during each experiment. When 1000 pulses are registered, the experiment is complete for that specific location of the Wiper Blade.

****
 Step 118
****

Using the Fibre Optic Sensors to count components during the Experiments:

If the Input (X11) is on when Marker (M150) is on, the Marker (M23) and Flag Marker (M22) will be pulsed. These Markers can also be pulsed if any of the Inputs (X3), (X4) or (X5) come on while Marker (M150) is on.

Note: The Fibre Optic Inputs (X11), (X3), (X4) and (X11) will be used to count the number of components during the Experiments.

```
*********
  Step 129
*********
```
Start the Blockage Timer:

If the Markers (M22) and (M150) are set while Marker (M9) is off, the Marker (M24) will be set.

Note: These Markers are used to start the Blockage Timer in step 138.

```
********
  Step 133
*********
```
Deciding when a Blockage has occurred:

If the Markers (M23) and (M150) are set while Timer (T30) is off, the Marker (M24) will be set. Marker (M25) will reset Marker (M24) when it comes on.

Note: Marker (M24) will be continually reset as long as the Timer (T30) does not time out completely. If there is no pulse from Marker (M22) over a 30 second interval, the Marker (M24) will not be reset which will indicate that a blockage has occurred.

```
*********
  Step 138
*********
```
Time Delay for Blockages:

If Marker (M22) is set while Marker (M9) is off the Timer (T30) will begin timing out. If Marker (M24) is set, Timer (T30) will come on.

Note: The Timer (T30) controls the period of time allowing components to be Rejected and/or Passing by the Wiper Blade Trap. If no component is Rejected or Passes by the trap over a 30 second interval it is assumed that a Blockage has occurred.

```
*********
  Step 144
*********
```

Blockage Management:

When Timer (T30) times out the Marker (M12) will be pulsed.

Note: This Marker (M12) will only come on after a Blockage has occurred at the Wiper Blade Trap location.

```
*********
  Step 147
*********
```

Counting the number of Blockages:

When Marker (M12) is pulsed, the Counter (C6) will be incremented by a value of 1 and the Marker (M9) will be set.

Note: Counter (C6) will be used to count the number of blockages that occur during each experiment. The Marker (M9) continues with the Blockage Management.

```
*********
  Step 152
*********
```

Turning on the Warning light:

If the Marker (M9) comes on while the Markers (M151) and (M152) are off, the Timer (T150) will begin timing out. After 2 seconds the Timer (T150) comes on and the Output (Y17) will switch on.

Note: When a blockage has occurred a time lag of two seconds will be allowed before the Warning Light (Y17) switches on.

****
  Step 160
****
Controlling the period of time between Flashing on and off:

When the Output (Y17) comes on, the Timer (T151) begins timing out. When 2 seconds have elapsed, Timer (T151) will come on which sets the Marker (M151).

Note: The light has been on for two seconds; having set the Output (Y17) it can now be switched off by setting the Marker (M151). When the Output (Y17) switches off the Marker (M151) will switch off and the Timer (T150) will be ready to come back on. The result will be a Flashing light which comes on and off at two second intervals.

****
  Step 166
****
Controlling the number of Flashes of the light:

When the Timer (T151) comes on, the Counter (C90) will increment by a value of one. The Counter (C90) has a maximum value of 5.

Note: The Timer (T151) will be used along with the Counter (C90) to give a precise number of Flashes before any action is taken to clear the Blockage. In this case the light will flash on and off five times continuously.

****
  Step 173
****
Taking action to Clear the Blockage:

If the Counter (C90) or the Marker (M77) comes on while the Timer (T55) is off, the Output (Y10) will come on. When the Output (Y10) comes on the Timer (T55) will begin timing out, after 3 seconds Timer (T55) will come on and the Output (Y10) will switch off.

Note: The Air Blast (Y10) will come on as soon as the Counter (C90) times out. The Blast of air will stay on for 3 seconds, which should clear the Blockage under the Wiper Blade.

****
  Step 183
****

Resetting Blockage Markers, Timers and Counters:

When Output (Y10) goes on along with Timer (T55), the Marker (M152) will be set while Counter (C90) and Timer (T150) are reset.

Note: When the Blockage has been cleared the Blockage Markers, Timers and Counters are reset for future experiments.

****
  Step 190
****

<u>Reset the Remaining Blockage Markers:</u>

When the Timer (T55) comes on, the Markers (M9) and (M77) are reset, while Marker (M25) is pulsed.

Note: As soon as the Timer (T55) comes on, the remaining Blockage Markers are reset.

****
  Step 195
****

Process is now Reset:

When the Marker (M9) goes off, the Marker (M152) will be reset.

Note: As soon as Blockage Marker goes back on the Marker (M152) will be reset and the process can now continue.

****
  Step 197
****

Store the results of each Experiment and calculate the Overall Performance: When

Counter (C10) comes on or Input (X22) is switched on, the Marker (M80) will be pulsed.

Note: A quantity of 1000 components has to be reached before each experiment will be

complete finished. At this stage the Counter (C10) will come on and Marker (M80) will

be pulsed. (A Toggle Switch Input (X22) can be used to demonstrate the PLC program

operations, without waiting for one thousand parts to be counted).

****
  Step 201
****

Store the Results:

When the Marker (M80) comes on, the Counter values in (C2), (C11), (C5), (C6) and

(C10) are stored in the Data Registers (D22), (D23), (D5), (D6) and (D25) respectively.

The Marker (M120) will be pulsed when the information is stored.

Note: Storing the experiment results.

Description	**Counter**	*Data Register*
Number Passed by Trap	C2	D22
Rejection Number at Trap	C11	D23
Height Counter	C5	D5
Blockage Number at Trap	C6	D6
Experiment Quantity	C10	D25

****
  Step 229
****

Start Calculations on Experiment Data:

When Marker (M120) comes on the value stored in Data Register (D6) will be multiplied

by 20 and stored in Data Register (D10). The Marker (M130) will then be pulsed.

Note: $(D6 * 20) = D10$

****
Step 239
****

When Marker (M130) comes on the value stored in Data Register (D22) will be subtracted by the value stored in Data Register (D10), the result will then be stored in Data Register (D11). The Marker (M131) will then be pulsed.

Note: $(D22 - D10) = D11$

****
Step 249
****

When the Marker (M131) comes on, the value stored in Data Register (D11) will be multiplied by 100 and stored in Data Register (D9). The Marker (M134) will then be pulsed.

Note: $(D11 * 100) = D9$

****
Step 259
****

When the Marker (M134) comes on, the value stored in Data Register (D9) will be divided by the value stored in Data Register (D25), the result will be stored in Data Register (D12).). The Marker (M132) will then be pulsed.

Note: $(D9 \div D25) = D12$

Performance Number = D12

$$D12 = \frac{[D22 - (D6 * 20)] * 100}{1000}$$

****
Step 269

****

Logging all of the Experiment Data into Registers:

When Marker (M120) comes on the value stored in Data Register (D22) will be moved into Data Register ($D102^z$). The value stored in Data Register (D23) will be moved into Data Register ($D103^z$). The value stored in Data Register (D6) will be moved into Data Register ($D104^z$). After the Analytical calculations are performed the value stored in Data Register (D12) will be moved into Data Register ($D105^z$). The Marker (M135) will then be pulsed.

Note: At this point the results of each experiment are stored.

****
  Step 293
****

Increment the "Z" Registers by a value of ten after each Experiment:

When the Marker (M135) is pulsed a value of 10 will be added to the "V" register and stored as the new value of "V". This new value will be moved from the "V" register to a "Z" register.

Note: The data obtained from each experiment will be stored in incremental registers within the PLC program e.g.

Experiment Number	Blockage Number	"Z" Registers
No 1	D6	$D104^z$
No 2	D6	$D114^z$
No 3	D6	$D124^z$

****
  Step 306
****

Manually Resetting the "Z" Registers:

When the Input (X21) comes on, the "V" and "Z" registers will be reset to zero.

Note: Having Recorded the Experiment data, the "Z" registers will be manually reset by operating the Toggle switch (X21).

****
  Step 306
****
Determine the Maximum Performance from each individual Experiments:

When Marker (M132) comes on, the Experiment Performance result stored in Data Register (D12) will be compared with the Maximum Performance result stored in Data Register (D60). If (D12)>(D60) the value in Data Register (D12) will be moved into the Data Register (D60) and will become the Maximum Performance result for future calculations. Marker (M29) will then be set. Marker (M29) will be used to set Marker (M36), when Marker (M36) comes on the Maximum Performance value stored in Data Register (D60) will be moved into the "Z" Register (D106^Z).

Note: Determine the Maximum Performance result from the experiments and log the result continually.

****
  Step 333
****
When the Marker (M36) comes on, the Timer (T231) will begin timing out and after 3 seconds it will come on.

Note: The Timer (T231) will be used to reset markers later.

****
  Step 337
****
When the Timer (T231) comes on, the Marker (M36) will be reset along with the Timer (T231).

Note: Timer (T231) will be used to reset itself along with Marker (M36). Marker (M36) will have to be continually reset allowing the Data Register (D60) to transfer its results into the "Z" Register (D106^Z).

****
  Step 341
****
Controlling the Pin Cylinders on the Wiper Blade Trap:

When the Input (X1) comes on, the Marker (M1) will be set.

Note: When the Guided Cylinder is in the Home Position the Reed switch (X1) will come on. When (X1) comes on the Marker (M1) used to control the Pin Cylinders which lock the Wiper Blades Angle in position will be set.

****
  Step 343
****
Controlling the Pin Cylinders and locking the Angle of the Wiper Blade:

If any of the Markers (M1), (M106) or (M108) come on the Output (Y12) will be switched on.

Note: The Markers (M1), (M106) or (M108) can be used to control the Pin Cylinders (Y12), this will lock the Wiper Blade's Angle in position.

****
  Step 347
****
If the Marker (M100) is on and the Markers (M106) and (M108) are off, the Marker (M1) will be reset.

Note: These Markers will be used to reset the Marker (M1) that will turn off the Output (Y12) so that the Angle of the Wiper Blade can be continually changed.

****
  Step 351
****
Controlling the Height of the Wiper Blade Trap:

When the Input (X1) comes on, the Marker (M2) will be set.

Note: When the Guided Cylinder is in the Home Position the reed switch (X1) will come

on. When (X1) comes on the Marker (M2) that controls the Pin Cylinder and locks the

Wiper Blade (Height) in position, will be set.

****
  Step 353
****
Turning on the Pin Cylinder (Y14):

If any of the Markers (M2), (M105) or (M109) come on, the Output (Y14) will go on.

Note: Any of the three Markers can be used to control the Pin Cylinder (Y14), this will

lock the Wiper Blade's Height in position. These Markers will be used on a continuous

basis during the experiments.

****
  Step 357
****
 Turning off the Pin Cylinder (Y14):
If the Marker (M101) is on and the Markers (M105) and (M109) are off, the Marker (M2)

will be reset.

Note: These Markers will be used to reset the Marker (M2) that will turn off the Output

(Y14) so that the Height of the Wiper Blade can be changed continually.

Result:

Output	Pin Cylinder	FUNCTION

Y12	Pin Cylinder 1	Locks the Angle of the Wiper Blade
Y12	Pin Cylinder 2	Locks the Angle of the Wiper Blade
Y14	Pin Cylinder 3	Locks the Height of the Wiper Blade

****
 Step 361
****

Change the Height of the Wiper Blade during the Experiments:

If the Markers (M31) and (M11) go on, the Marker (M3) will be pulsed. When the

Marker (M31) comes on a value of (102) will be moved into the Data Register (D13).

Change the Height of the Wiper Blade during a Demonstration:

If the Input (X23) comes on the Marker (M3) will be pulsed and a value of (6) will be put

into Data Register (D13).

Note: The height obtained by the Wiper Blade depends on the number stored in Data

Register (D13). Input (X23) is a Toggle Switch used by the operator.

****
 Step 380
****

Changing the Height of the Wiper Blade back to its starting position during the

Experiments (Zero Height):

When Marker (M32) comes on, the Marker (M4) will be pulsed and a value of (90) will

be moved into Data Register (D17). The Marker (M32) will then be reset.

Note: The Stepping Motor will move the Wiper Blade back to its original position before

adjusting the angle.

****
 Step 389
****

Change the Angle of the Wiper Blade during the Experiments:

If the Markers (M33) comes on, the Marker (M5) will be pulsed. When the Marker (M33)

comes on a value of 1 will be moved into the Data Register (D7).

Change the Angle of the Wiper Blade during a Demonstration:

If the Input (X24) comes on the Marker (M5) will be pulsed and a value of 2 will be put

into Data Register (D7).

Note: Changing the Angle of the Wiper Blade moves depends on the number stored in

Data Register (D7). Input (X24) is a Toggle Switch used by the operator.

****
  Step 407
****
Changing the Angle of the Wiper Blade back to its starting position after the

Experiments (Zero Angle):

When Marker (M34) comes on, the Marker (M6) will be pulsed and a value of 1 will be

moved into Data Register (D19).

Note: The Stepping Motor will move the Wiper Blade back to its original position (Zero

Angle) at the end of the experiments.

****
  Step 415
****
Changing the Height:

When the Marker (M3) is pulsed, a value of 2 will be added to Data Register (D0) and the

new value will be stored as (D0).

Note: The Data Register (D0) must have a value greater than 1.

****
  Step 423
****
Changing to Zero Height:

When the Marker (M4) is pulsed, a value of 2 will be added to Data Register (D1) and the

new value will be stored as (D1).

Note: The Data Register (D1) must have a value greater than 1.

****
 Step 431
****
<u>Changing the Angle:</u>

When the Marker (M5) is pulsed, a value of 2 will be added to Data Register (D2) and the

new value will be stored as (D2).

Note: The Data Register (D2) must have a value greater than 1.

****
 Step 439
****
<u>Changing to Zero Angle:</u>

When the Marker (M6) is pulsed, a value of 2 will be added to Data Register (D3) and the

new value will be stored as (D3).

Note: The Data Register (D3) must have a value greater than 1.

****
 Step 447
****
<u>Changing the Height:</u>

When Marker (M3) is pulsed, the value stored in Data Register (D0) will be compared to

a value of 1, if it is greater than 1 the Marker (M7) will be set. As soon as the Marker

(M7) comes on a Marker (M10) will be set.

Note: A decision to adjust the height is made.

****
  Step 451
****
<u>Changing to Zero Height:</u>

When Marker (M4) is pulsed, the value stored in Data Register (D1) will be compared to

a value of 1, if it is greater than 1 the Marker (M37) will be set. As soon as the Marker

(M37) comes on a Marker (M45) will be set.

Note: The height of the Wiper Blade will be adjusted back to zero height.

****
  Step 467
****
<u>Changing the Angle:</u>

When Marker (M5) is pulsed, the value stored in Data Register (D2) will be compared to

a value of 1, if it is greater than 1 the Marker (M17) will be set. As soon as the Marker

(M17) comes on a Marker (M20) will be set.

Note: A decision to adjust the angle is made.

****
  Step 477
****
<u>Changing to Zero Angle:</u>

When Marker (M6) is pulsed, the value stored in Data Register (D2) will be compared to

a value of 1, if it is greater than 1 the Marker (M48) will be set. As soon as the Marker

(M48) comes on a Marker (M40) will be set.

Note: A decision to adjust the angle back to the zero angle position is made.

****

Step 487
****
<u>**Changing the Angle:**</u>

When Marker (M20) comes on, Data Registers (D0), (D1) and (D3) are reset to a value of

zero. The Timer (T1) begins timing out and after 2 seconds it will come on.

Note: Resetting the Data Registers prevents any conflicting signals, as the Stepping Motor

can only receive one command at a time, in this case changing the angle.

****
Step 499
****
<u>**Changing to Zero Height:**</u>

If Marker (M45) comes on while Marker (M62) is off, Data Registers (D2), (D3) and

(D0) are reset to a value of zero. The Timer (T4) begins timing out and after 2 seconds it

will come on. Marker (M101) is also set which will reset (Y14).

Note: Resetting the remaining Data Register prevents any conflicting signals as the

Stepping Motor can only receive one command at a time, in this case zero height.

****
Step 512
****
<u>**Changing to Zero Angle:**</u>

When Marker (M40) comes on, Data Registers (D0), (D2) and (D4) are reset to a value of

zero. The Timer (T5) begins timing out and after 2 seconds it will come on.

Note: Resetting the remaining Data Register prevents any conflicting signals as the

Stepping Motor can only receive one command at a time, in this case zero angle.

****
Step 524
****

Changing the Height:

When Marker (M10) comes on, Data Registers (D1), (D2) and (D3) are reset to a value of zero. The Timer (T3) begins timing out and after 2 seconds it will come on. Marker (M101) is also set which resets (Y14).

Note: Resetting the remaining Data Register prevents any conflicting signals as the Stepping Motor can only receive one command at a time, in this case the height.

****
  Step 534
****
Changing the angle:

If the Marker (M20) comes on, Input (X2) comes on and Marker (M63) is off, the Marker (M100) will be set. The Timer (T20) begins timing out and after 1 second it will come on.

Note: Marker (M20) will start the process in changing the Angle, if the Guided Cylinder is in the Extended position (X2) will be on and the Marker (M100) will be set which will disengage the Pin Cylinder (Y12).

****
  Step 543
****
Time allowance for disengaging the Pin cylinder (Y12):

If the Timer (T20) is on along with Input (X2) the Timer (T21) will begin timing out.

Note: This Timer allows sufficient time for the Pin Cylinder (Y12) to be reset.

****
  Step 548
****
When Timer (T21) times out, the Marker (M28) will be reset.

****
  Step 550
****
Timing Control of the Guided Cylinder:

When Timer (T1) comes on, the Marker (M27) will be set.

Note: The Marker (M27) will operate the Guided Cylinder at the correct time.

****
Step 552
****
Changing to Zero Angle:

When the Marker (M40) comes on and the Input (X2) comes on the Marker (M100) will

be set.

Note: The Marker (M100) will disengage the Pin Cylinder (Y12).

****
Step 558
****
When Timer (T22) comes on along with Input (X2), the Timer (T23) will begin timing

out after 3 seconds it will come on.

Note: There is a 3 second time delay allowed before the next command.

****
Step 563
****
When the Timer (T23) comes on, the Marker (M108) will be reset.

Note: The Marker (M108) resets the Pin Cylinder (Y12) when the Wiper Blade is

required to move about an Angle.

****
Step 565
****
Timing control of the Guided Cylinder:

When the Timer (T5) comes on, the Marker (M73) will be set.

Note: The Marker (M73) will operate the Guided Cylinder at the required time.

****
Step 567
****
 <u>Timing control of the Guided Cylinder:</u>

When the Timer (T3) comes on, the Marker (M59) will be set.

Note: The Marker (M59) will operate the Guided Cylinder at the required time.

****
Step 569
****
 <u>Timing control of the Guided Cylinder:</u>

When the Timer (T4) comes on, the Marker (M61) will be set.

Note: The Marker (M61) will operate the Guided Cylinder at the required time.

****
Step 571
****
<u>Controlling the Guide Cylinder using the Correct Marker at the Correct Time:</u>

If the Marker (M27) is on and the Marker (M65) is off, the Output (Y13) goes on.

If the Marker (M59) is on and the Marker (M67) is off, the Output (Y13) goes on.

If the Marker (M61) is on and the Marker (M60) is off, the Output (Y13) goes on.

If the Marker (M73) is on and the Marker (M47) is off, the Output (Y13) goes on.

Note: There are a number of Markers that can control the Guided Cylinder (Y13), in this

situation there are four circumstances to consider as shown below.

<u>The Four Circumstances to consider:</u>

(A) = Guided Cylinder Extends to move the Height of the Wiper Blade.

(B) = Guided Cylinder Extends to move the Height of the Wiper Blade (Zero Height).

(C) = Guided Cylinder Extends to move the Angle of the Wiper Blade.

(D) = Guided Cylinder Extends to move the Angle of the Wiper Blade (Zero Angle).

****

Step 583

****

<u>**Time allowed to Extend the Guided Cylinder:**</u>

When the Marker (M73) comes on the Timer (T6) begins timing out. After .8 of a second

Timer (T6) will come on.

Note: This is the time allowed to extend the Guided Cylinder (Y14).

****

Step 587

****

<u>**Time allowed to Extend the Guided Cylinder:**</u>

When the Marker (M27) comes on the Timer (T2) begins timing out. After point eight of

a second Timer (T2) will come on.

Note: This is a secondary time allowed for extending the Guided Cylinder (Y14).

****

Step 591

****

<u>**Controlling the Vibratory Bowl:**</u>

If any of the Markers (M10), (M20), (M45) or (M40) come on along with the Input (X0),

the Marker (M350) will be set.

Note: If the Vibratory Bowl Sensor (X0) is on with any of the Markers (M10), (M20),

(M45) or (M40) the Vibration Bowl Marker (M350) will be set, this will energise the

Vibratory Bowl Relay which will stop the Vibratory bowl from operating.

****

Step 597

****

<u>**Vibratory Bowl Relay Switched On:**</u>

When Marker (M350) comes on the Output (Y7) goes on.

Note: The Vibratory Bowl Relay (Y7) will switch off the power to the Vibration Bowl as

soon as it is energised.

****
  Step 599
****
Switching the Vibratory Bowl back on:

If any of the Markers (M68), (M69), (M58) or (M75) go on the Marker (M350) will be reset.

Note: If the Marker (M350) is reset the Vibration Bowl Relay will switch off and the Vibration Bowl will come back on.

Controlling the Stepping Motor Outputs:

The Stepping Motor Outputs (Y0), (Y1), (Y2) and (Y3) will have to be controlled by a series of program conditions. These conditions consist of Inputs, Markers and Timers that regulate the required Outputs, in a controlled sequence at the correct time. In this case the Stepping Motor will be moved through either a Clockwise or Anticlockwise rotation using Single Phase Excitation with a Step Angle of (1.8^0).

The Stepping Motor will be used to provide rotational movement for four different situations this can be seen form the chart on the next page. For the purpose of simplicity and to avoid confusion, the PLC program operations involved in changing the height of the Wiper Blade will be discussed in detail using the program steps between (604) & (963). The other operations that are not explained are very similar.

Control Marker	Adjust	Rotation	Output Sequence				Conditions
M10	Change Height	Clockwise	Y0	Y1	Y2	Y3	Inputs, Timers, Markers
M20	Change Angle	Clockwise	Y0	Y1	Y2	Y3	Inputs, Timers, Markers
M40	Zero Angle	Anticlockwise	Y3	Y2	Y1	Y0	Inputs, Timers, Markers
M45	Zero Height	Anticlockwise	Y3	Y2	Y1	Y0	Inputs, Timers, Markers

****

Step 604
****
<u>Rising the Wiper Blade Height:</u>

Output (Y0) will come on, if the following PLC operating conditions are satisfied.

Description	Inputs/Timers/Markers	Logic On/Off
Pulse Marker	M104	Off
Control Marker	M10	On
Timer	T3	On
Timer (High Speed)	T208	Off
Input (Reed Switch)	X2	On

When the Output (Y0) comes on, it is latched on as long as the following PLC operating

conditions are satisfied.

Description	Inputs/Timers/Markers	Logic On/Off
Output	Y0	On
Control Marker	M10	On
Control Marker	M45	Off
Input (Reed Switch)	X2	On
Timer (High Speed)	T208	Off

****
Step 671
****
<u>Controlling the High Speed Timer on the Output (Y0):</u>

The High Speed Timer (T208) will be controlled by a number of PLC logic conditions

when these conditions are satisfied the timer begins timing out.

Description	Inputs/Timers/Markers	Logic On/Off
Pulse Marker	M104	Off
Control Marker	M10	On
Timer	T3	On
Input (Reed Switch)	X2	On
Control Marker	M20	Off
Control Marker	M45	Off
Control Marker	M40	Off

The High Speed Timer (T209) will stay on while the Output (Y1) stays on. When the

Timer (T208) times out after .5 of a second, the Latch on the Output (Y0) will be broken

turning off (Y0), the PLC operating conditions for Output (Y1), are satisfied.

****
 Step 710
****
Rising the Wiper Blade Height:

The Output (Y1) will come on, when the following PLC operating conditions are

satisfied.

Description	Inputs/Timers/Markers	Logic On/Off
Control Marker	M10	On
Timer	T3	On
Timer (High Speed)	T208	On
Timer (High Speed)	T209	Off
Input (Reed Switch)	X2	On

When the Output (Y1) comes on, it is latched on as long as the following PLC operating

conditions are satisfied.

Description	Inputs/Timers/Markers	Logic On/Off
Output	Y1	On
Control Marker	M10	On
Control Marker	M45	Off
Timer (High Speed)	T209	Off
Input (Reed Switch)	X2	On

****
 Step 759
****
Controlling the High Speed Timer on the Output (Y1):

The High Speed Timer (T209) will be controlled by a number of PLC operating

conditions when these conditions are satisfied the timer begins timing out. After .5 of a

second the timer will come on.

Description	Inputs/Timers/Markers	Logic On/Off
Control Marker	M10	On
Timer	T3	On

Timer	T208	On
Input (Reed Switch)	X2	On
Control Marker	M20	Off
Control Marker	M45	Off
Control Marker	M40	Off

The Timer (T209) will stay on while the Output (Y1) stays on. When Timer (T209) times out after (.5) of a second, the Latch on the Output (Y1) will be broken and the PLC operating conditions for Output (Y2) will be satisfied.

****
 Step 792
****
Rising the Wiper Blade Height:

For the Output (Y2) to come on, the following PLC operating conditions must be satisfied.

Description	Inputs/Timers/Markers	Logic On/Off
Control Marker	M10	On
Timer	T3	On
Timer (High Speed)	T209	On
Timer (High Speed)	T210	Off
Input (Reed Switch)	X2	On

When the Output (Y2) comes on, it is latched on as long as the following PLC operating conditions are satisfied.

Description	Inputs/Timers/Markers	Logic On/Off
Output	Y2	On
Control Marker	M10	On
Control Marker	M45	Off
Timer (High Speed)	T210	Off
Input Guide Cylinder Reed Switch	X2	On

****
 Step 841
****
Controlling the High Speed Timer on the Output (Y2):

The High Speed Timer (T209) will be controlled by a number of PLC operating conditions when these conditions are satisfied the timer begins timing out.

Description	Inputs/Timers/Markers	Logic On/Off
Control Marker	M10	On
Timer	T3	On
Timer	T209	On
Input (Reed Switch)	X2	On
Control Marker	M20	Off
Control Marker	M45	Off
Control Marker	M40	Off

The Timer (T210) will stay on while the Output (Y2) stays on. When Timer (T210) times out after (.5) of a second, the Latch on the Output (Y2) will be broken and the PLC operating conditions for Output (Y3) will be satisfied.

****
  Step 874
****
Rising the Wiper Blade Height:

For the Output (Y3) to come on, the following PLC operating conditions must be satisfied.

Description	Inputs/Timers/Markers	Logic On/Off
Control Marker	M10	On
Timer	T3	On
Timer (High Speed)	T210	On
Input (Reed Switch)	X2	On
Timer (High Speed)	T211	Off

When the Output (Y3) comes on, it is latched on as long as the following PLC logic conditions are satisfied.

Description	Inputs/Timers/Markers	Logic On/Off
Output	Y3	On
Control Marker	M10	On
Control Marker	M45	Off
Input (Reed Switch)	X2	On
Timer (High Speed)	T213	Off

Stop the Stepping Motor when it has completed the required number of Cycles:

If the Input (X2) is off and the Marker (M10) is on, the Counter (C3) will increment by a value of 1. When the value in Counter (C3) equals the value in (D13) the Output Sequence to the stepping motor will be stopped.

****
 Step 935
****

Controlling the High Speed Timer on the Output (Y3):

The High Speed Timer (T211) will be controlled by a number of PLC operating conditions when these conditions are satisfied the timer begins timing out.

Description	Inputs/Timers/Markers	Logic On/Off
Control Marker	M10	On
Timer	T3	On
Timer	T210	On
Input (Reed Switch)	X2	On
Control Marker	M20	Off
Control Marker	M45	Off
Control Marker	M40	Off

The Timer (T211) will stay on while the Output (Y3) stays on. When Timer (T211) times out after .5 of a second, the Latch on the Output (Y2) will be broken and the Pulse Marker (M104) will be pulsed. When Marker (M104) is pulsed the PLC operating conditions for Output (Y0) will be satisfied again and the entire process begins again. This ends when the value in the Counter (C3) equals the value in the Data Register (D13).

****
 Step 980
****

Reset the Pin Cylinder (Y14) (Wiper Blade Height Change):

When the Counter (C3) comes on, the Markers (M64) and (M105) will be set, the Data Register (D13) will be reset and the Timer (T11) will begin timing out. When the Timer (T11) has fully timed out after 2 seconds it will come on.

Note: The Marker (M105) will reset the Pin Cylinder (Y14) the Timer (T11) allows 2

seconds for this to occur. The Pin Cylinder locks the Wiper Blade at that specific Height.

Resetting the Data Register (D13) means that the Cycle can begin again.

```
*********
  Step 989
*********
```

<u>Resetting the Guide Cylinder (Wiper Blade Height Change) :</u>

When the Timer (T11) comes on a Marker (M67) will be reset while the Timer (T18) will

begin timing out. After 2 seconds the Timer (T18) will come on. If the Timer (T11) is off

and the Input (X1) is on the Control Marker (M10) will be reset.

Note: The Control Marker (M10) will be reset when the Guided Cylinder is in the home

position and the Reed Switch (X1) is on.

```
*********
  Step 999
*********
```

<u>Turning the Vibration Bowl back on (Wiper Blade Height Change):</u>

If the Timers (T11) and (T18) come on when the Marker (M10) goes off, the Marker

(M69) will be set.

Note: When the Marker (M69) is set this will switch off the Vibratory Bowl Relay and

the Vibratory Bowl will come back on.

```
**********
  Step 1003
**********
```

<u>Resetting the Pin Cylinders (Wiper Blade Angle Change):</u>

When the Counter (C7) comes on the Data Register (D7) will be reset to a value of zero

and the Timer (T100) will begin timing out. After 3 seconds the Timer (T100) will come

on. When the Timer (T100) comes on the Marker (M106) will be set. When the Marker

(M106) comes on, the Timer (T12) will begin timing out. After 2 seconds the Timer

(T12) will come on.

Note: There is time allowed so that the Pin Cylinders can be locked in position after the Wiper Blade has moved through the required Angle. Setting the Marker (M106) will reset the Pin Cylinders (Y12).

****
   Step 1019
****
Resetting the Guide Cylinder (Wiper Blade Angle Change):

When the Timer (T12) comes on the Marker (M65) will be reset and the Marker (M20) will be set.

Note: The control Marker (M20) will be reset when the Wiper Blade has moved through the required angle. The Marker (M65) resets the Guided Cylinder (Y13).

****
   Step 1022
****
Resetting Pin Cylinders (Wiper Blade Angle Change):

When the Counter (C26) comes on the Markers (M109) and (M62) will be set. The Timer (T14) will begin timing out and after 1 second it will come on.

Note: Marker (M109) resets Pin Cylinder (Y14) locking the height of the Wiper Blade in position. The Marker (M109) resets the Guided Cylinder (Y13).

****
   Step 1029
****
Resetting Control Marker (Wiper Blade Height Change):

When the Timer (T14) comes on, the Marker (M60) will be set and the Timer (T19) will begin timing out. After 1 second the Timer (T19) will come on. If Timer (T4) is off and Input (X1) is on, the Marker (M45) will be reset.

Note: The Control Marker (M45) must be reset after the Wiper Blade has returned to its starting position (Zero Height).

****
   Step 1038
****

Switching the Vibration Bowl back on:

If the Timers (T14) and (T19) are set and the Marker (M45) is off, the Marker (M58) will

be reset.

Note: The Marker (M58) is used to switch off the Vibration Bowl relay this allows the

Vibration Bowl to come back on.

****
   Step 1042
****

Resetting the Pin Cylinder (Wiper Blade Angle Change):

When the Counter (C29) comes on, the Marker (M108) will be set. When Marker (M108)

comes on the Timer (T24) will begin timing out. After .5 of a second Timer (T24) will

come on.

Note: The Marker (M108) will reset the Pin Cylinder (Y12) locking the Wiper Blade

height in position.

****
   Step 1048
****

Reset the Guided Cylinder (Wiper Blade Angle Change):

When the Timer (T24) comes on the Markers (M40) and (M73) will be reset.

Note: The Control Marker (M40) must be reset after the Angle of the Wiper Blade has

been changed back to its starting position (Zero Angle). The Guided Cylinder (Y13) will

return to its home position when the Marker (M73) is reset.

****
   Step 1051
****

Resetting Markers, Counters, Timers and Data Registers (Height Change):

When the Input (X1) comes on and the Marker (M69) is set, the following Markers,

Counters, Timers and Data Registers shown in the chart below will be reset.

Note: Guided Cylinder (X1) will be in the home position and the Vibration Bowl relay

(Y7) will be switched off turning the Vibration Bowl back on.

Markers	Data Registers	Timers	Counters
M8	D0	T11	C3
M59	D1	T18	
M64	D2		
M67	D3		
M69	D4		
M101			
M105			

****
  Step 1071
****

<u>Resetting Markers, Counters, Timers and Data Registers (Angle Change):</u>

When the Input (X1) comes on and the Marker (M65) is set, the following Markers,

Counters, Timers and Data Registers shown in the chart below will be reset.

Note: Guided Cylinder (X1) will be in the home position and the Vibration Bowl relay

(Y7) will be switched off, turning the Vibration Bowl back on.

Markers	Data Registers	Timers	Counters
M18	D4	T2	C7
M20	D7	T12	
M27			
M65			
M100			
M106			

****
  Step 1091
****

<u>Resetting Markers, Counters, Timers and Data Registers (Zero Height):</u>

When the Input (X1) comes on and the Marker (M58) is set, the following Markers,

Counters, Timers and Data Registers shown in the chart below will be reset.

Note: Guided Cylinder (X1) will be in the home position and the Vibration Bowl relay (Y7) will be switched off turning the Vibration Bowl back on.

Markers	Data Registers	Timers	Counters
M38	D0	T4	C27
M101	D1	T14	
M58	D2	T19	
M109	D3		
M110	D4		

When the Input (X27) is switched on the Counter (C5) will be reset.

When the Counter (C33) comes on the Markers (M7), (M17) and (M37) are reset.

Note: When the Start switch (X27) is turned on the Counter (C5) will be reset to zero.

When the Experiments are finished the Counter (C33) will come back on.

****
  Step 1129
****
<u>Resetting Markers, Counters, Timers and Data Registers (Zero Angle):</u>

When the Input (X1) comes on and the Marker (M74) is set, the following Markers, Counters, Timers and Data Registers shown in the chart on the next page.

Note: Guided Cylinder (X1) will be in the home position and the Vibration Bowl relay (Y7) will be switched off turning the Vibration Bowl back on.

Markers	Data Registers	Timers	Counters
M40	D0	T24	C29
M48	D1		
M73	D2		
M74	D3		
M100	D4		
M108	D19		

End Program.

************** Narrow Track Trap ****************
****

```
        X021
  0 ─────┤ ├──────┬──────────────────────────────────────────(Y012)
                  │
                  ├──────────────────────────────────────────(Y014)
                  │
                  └──────────────────────────────────────────(Y010)

        X023
  4 ─────┤ ├───────────────────────────────────────────────────(M1)

        M1
  6 ─────┤ ├──────────────────────────────────────────────────(Y006)

        X023
  8 ─────┤/├──────────────────────────────────────[RST    M1]

        X014
 10 ─────┤ ├──────────────────────────────────────[PLS    M5]

        M5
 13 ─────┤ ├───────────────────────────[ADD    D1    K1    D1]

        X011
 21 ─────┤ ├──────────────────────────────────────[PLS    M6]

        M6
 24 ─────┤ ├───────────────────────────[ADD    D2    K1    D2]

        Y006
 32 ─────┤ ├──────┬────────────────────[ADD    D1    D2    D3]
                  │
                  └────────────────────[CMP    D3    K500   M4]

        M4
 47 ─────┤ ├──────────────────────────────────────────────────(Y017)

        X026
 49 ─────┤ ├──────┬─────────────────────────────[ZRST   D0    D4]
                  │
                  └─────────────────────────────[RST    M4]

        X024
 56 ─────┤ ├───────────────────────────────────────────────────(M2)

        M2
 58 ─────┤ ├──────────────────────────────────────────────────(Y007)

        X024
 60 ─────┤/├──────────────────────────────────────[RST    M2]

 62 ───────────────────────────────────────────────────────[END]
```

269
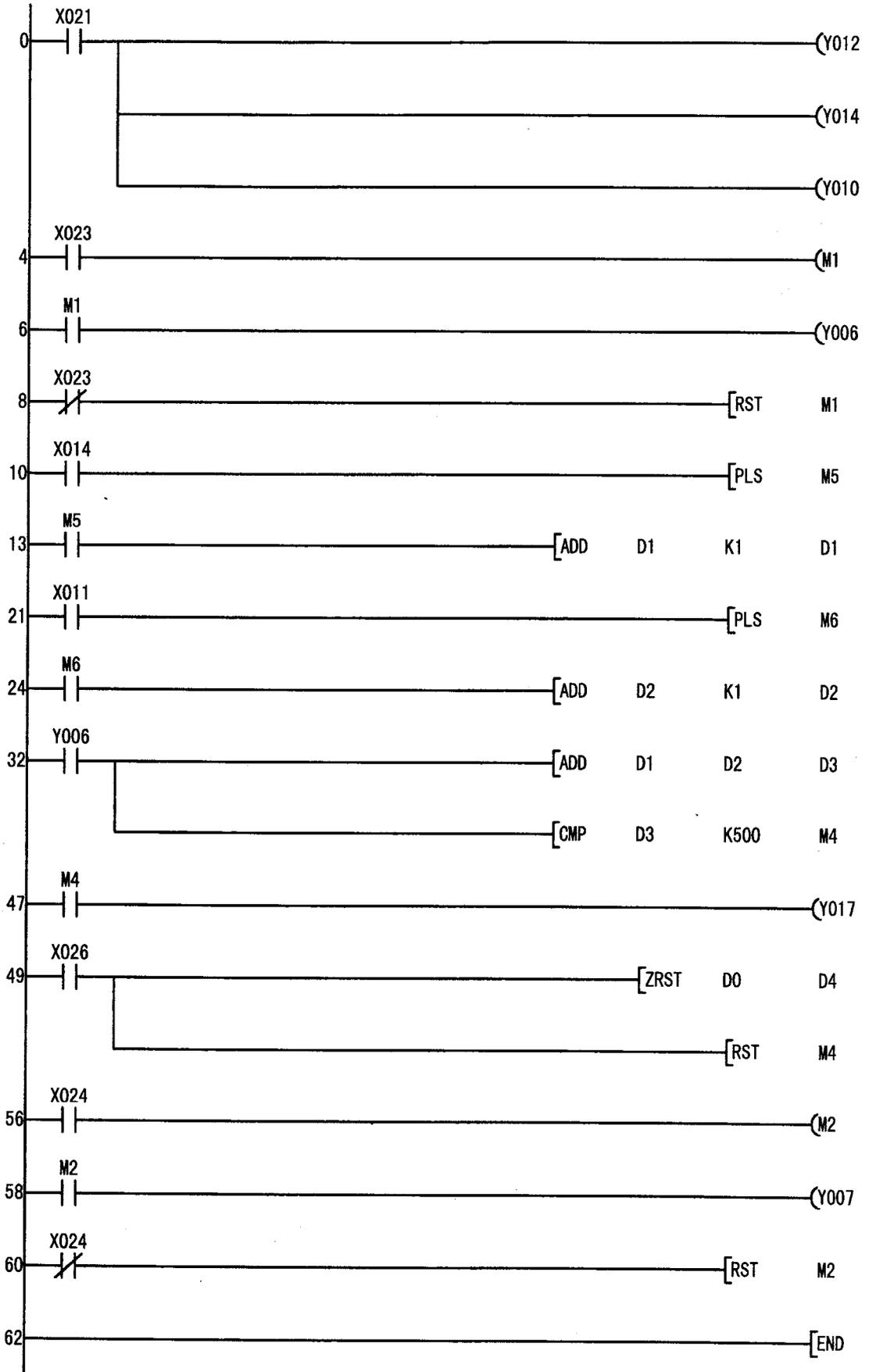
```
**************************************************************
*************** Narrow Track Commented PLC Program***************
**************************************************************
```

```
********
 Step 0
********
```
<u>Lock the Pin Cylinders on the Wiper Blade Trap:</u>

When the Input (X21) is switched on, the Outputs (Y12) and (Y14) come on together.

Note: The Toggle Switch (X21) switches on the Pin Cylinders (Y12), (Y14) locking the

Wiper Blade Trap in the optimum positions. This allows experiments to be conducted

using the Narrow Track Trap only.

```
********
 Step 4
********
```
<u>Turning on the Marker (M1):</u>

When the Input (X23) is switched on, the Marker (M1) is set.

Note: The Toggle switch (X23) is used to control the "On" position of the Narrow Track

Pin Cylinder (Y6) via a Marker (M1).

```
********
 Step 6
********
```
<u>Lock the Narrow Track Trap in position :</u>

When the Marker (M1) comes on, the Output (Y6) will be switched on.

Note: Marker (M1) controls the extended position of the Pin Cylinder (Y6).

```
********
 Step 8
********
```
<u>Resetting the position of the Narrow Track Trap:</u>

When the Input (X23) is switched off, the Marker (M1) will be reset.

Note: The Toggle switch (X23) will be used to reset the Narrow Track Pin Cylinder (Y6)

by resetting the Marker (M1).

****
  Step 10
****
<u>Counting the Components that are rejected by the Narrow Track Trap:</u>

When the Input (X14) comes on, the Marker (M5) is pulsed.

Note: The Fibre Optic Sensor (X14) is used to count the number of components that

"Fall-Off" the ledge at the Narrow Track Trap location. It does this by pulsing the Marker

(M5).

****
  Step 13
****
<u>Store the Rejection number in Data Register (D1):</u>

When the Marker (M5) is pulsed a value of "1" is added to the Data Register (D1) and

this will be stored as a new value in Data Register (D1).

Note: The Data Register (D1) will be used to determine the number of components that

fall-off (Back into the Bowl) at the Narrow Track Ledge location.

****
  Step 21
****
<u>Counting components that make it past the Narrow Track Trap:</u>

When the Input (X11) comes on, the Marker (M6) will be pulsed.

Note: The Fibre Optic Sensor (X11) is used to count the number of components that

successfully make it past the Narrow Track Trap. Each time a component passes by this

sensor, the Marker (M6) will be pulsed.

****
  Step 24
****
<u>Storing the number of components that pass by the Narrow Track successfully:</u>

When the Marker (M6) is pulsed a value of "1" is added to the Data Register (D2). Note:

The Data Register (D2) is used here to count the number of components that pass by the

Narrow Track Ledge successfully.

****
 Step 32
****

Determine when the Experiment Quantity has been reached:

When the Output (Y6) comes on, the value stored in Data Register (D1) will be added to the value stored in Data Register (D2), the combined value will be stored in (D3).

The value stored in Data Register (D3) will be constantly compared to the experiment quantity of 500 components. When (D3) is equal to 500 the Marker (M4) will be set.

Note: The Data Registers are used in this case to give the total number of components being experimented with at the Narrow Track Trap location and to determine when the experiment quantity has been reached.

****
 Step 47
****

Turn on the Warning Light when the Experiment is over:

When the Marker (M4) is set, the Output (Y17) will be switched on.

Note: The Marker (M4) is used to turn on the Warning Light (Y17) this will be observed by the operator who will take the necessary steps to begin a new experiment.

****
 Step 49
****

Resetting the Data Register Values:

When the Input (X26) is switched on, the Data Registers values from (D0) to (D4) are reset to a value of zero. The Marker (M4) is also reset at this point.

Note: At the beginning of a new experiment all Data Register values must obtain a value of zero, by switching on and off the Toggle Switch (X26) this will be preformed. By resetting the Marker (M4) the Warning Light will also be switched off.

****
   Step 56
****
Switching on the Vibratory Bowl Relay:

When the Input (X24) is switched on, the Marker (M2) will be set.

Note: The Toggle switch (X24) will be used to control the "On" position of the Vibration

Bowl Relay (Y7) via a Marker (M3).

****
   Step 58
****
Switching off the Vibratory Bowl:

When the Marker (M2) comes on, the Output (Y7) will be switched on.

Note: Marker (M2) controls the Vibration Bowl Relay (Y7).

****
   Step 60
****
Switching off the Vibratory Bowl Relay (Switching on the Vibratory Bowl):

When the Input (X24) is switched off, the Marker (M2) will be is reset.

Note: This step uses the Toggle switch (X24) to control the "Off" position of the

Vibratory Bowl Relay (Y7) by resetting the Marker (M2).

****
   Step 62
****
End Program

```
*************************************************
*************** Raised Ledge Trap ***************
*************************************************
        X021
   0────┤├──────┬──────────────────────────────────(Y012)
                │
                ├──────────────────────────────────(Y014)
                │
                └──────────────────────────────────(Y006)

        X023
   4────┤├───────────────────────────────────────────(M1)

        M1
   6────┤├──────────────────────────────────────────(Y011)

        X023
   8────┤/├──────────────────────────────[RST    M1]

        X011
  10────┤├───────────────────────────────[PLS    M2]

        M2
  13────┤├──────┬───────────────[ADD    D2    K1    D2]
                │
                └───────────────[CMP    D2    K500    M4]

        M4
  28────┤├──────────────────────────────────────────(Y017)

        X026
  30────┤├──────┬───────────────────[ZRST   D0    D3]
                │
                └───────────────────────[RST    M4]

        X024
  37────┤├───────────────────────────────────────────(M3)

        M3
  39────┤├──────────────────────────────────────────(Y007)

        X024
  41────┤/├──────────────────────────────[RST    M3]

  43──────────────────────────────────────────────[END]
```
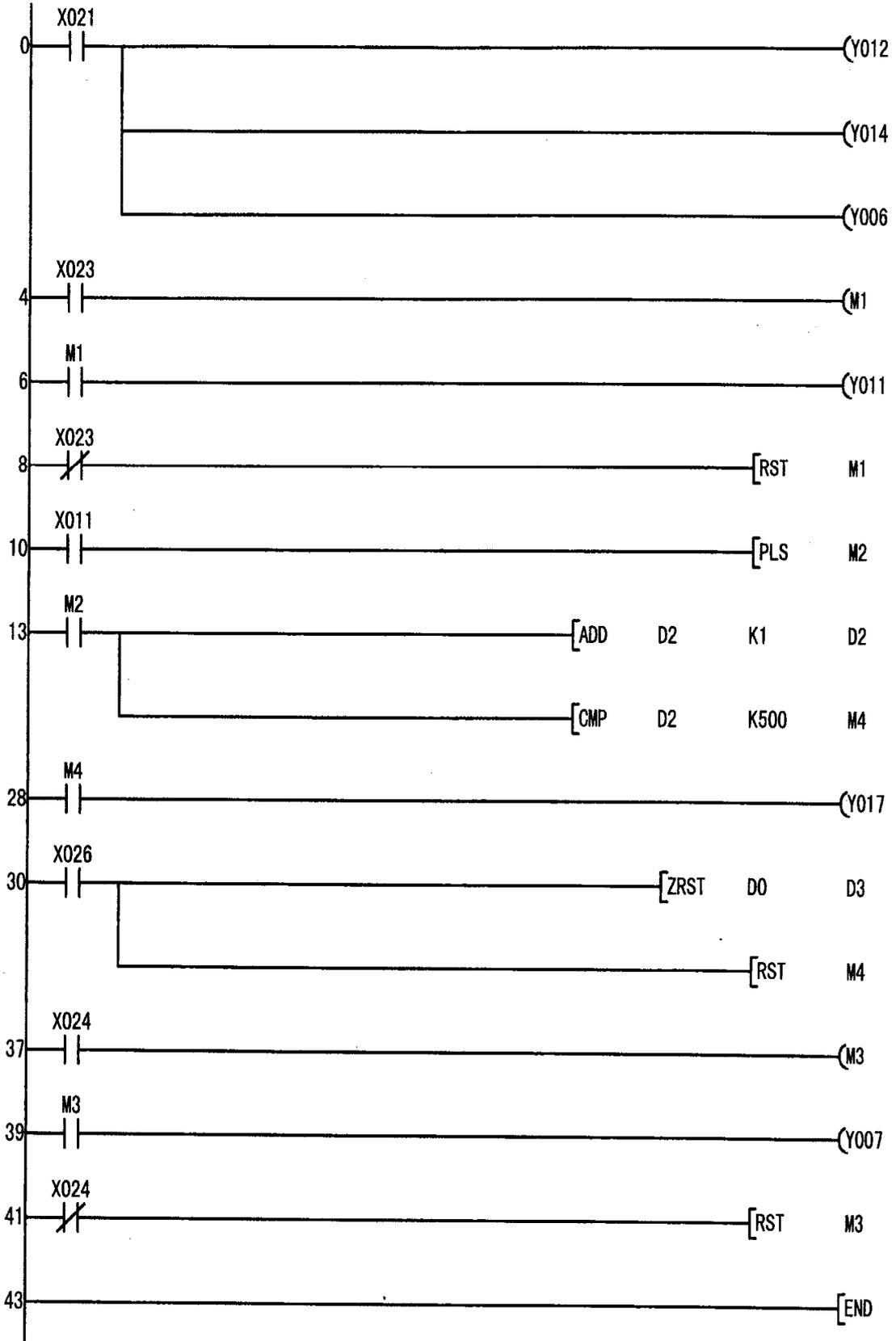
****
**************** **Raised Ledge Commented PLC Program** *****************
****

****
 Step 0
****

Locking the other two Traps in position:

When the Input (X21) is switched on, the Outputs (Y12), (Y14) and (Y6) will come on

together.

Note: Toggle Switch (X21) switches on the Pin Cylinders (Y12), (Y14) and (Y6) locking

the Wiper Blade Trap and the Narrow Ledge Trap in their optimum positions. This allows

experiments to be conducted using the Raised Ledge Trap only.

****
 Step 4
****

Locking the Raised Ledge Trap in Position:

When the Input (X23) is switched on, the Marker (M1) is set.

Note: This step uses a Toggle switch (X23) to control the "On" position of the Raised

Ledge Pin Cylinder (Y11) via a Marker (M1).

****
 Step 6
****

Locking the Raised Ledge Trap in Position:

When the Marker (M1) comes on, the Output (Y11) will be switched on.

Note: Marker (M1) controls the extended position of the Pin Cylinder (Y11).

****
 Step 8
****

<u>Resetting the Pin Cylinder (Y11):</u>

When the Input (X23) is switched off, the Marker (M1) is reset.

Note: The Toggle switch (X23) will be used to control the "Off" position of the Raised

Ledge Pin Cylinder (Y11) by resetting the Marker (M1).

****
 Step 10
****

<u>Count the number of components that pass by the Raised Ledge Trap:</u>

When the Input (X11) comes on, the Marker (M2) is pulsed.

Note: The Fibre Optic Sensor (X11) is used to count the number of components that

successfully pass by the Raised Ledge Trap location. The Marker (M2) will be pulsed for

each successfully orientated component.

****
 Step 13
****

<u>Determine when the Experiment Quantity is reached:</u>

When the Marker (M2) is pulsed a value of "1" is added to the value in Data Register

(D2), this will be stored as a new value in Data Register (D2).

Each time the Marker (M2) is pulsed the current value stored in Data Register (D2) will

be compared to a experiment value of 500. When (D2) is equal to that value, the Marker

(M4) will be set.

Note: The Data Registers (D2) will be used here to determine the number of components

that successfully pass at the Raised Ledge Trap location. This value this value will be

constantly compared to the experiment value of 500 components.

****
   Step 28
****

<u>**Turn on the Warning Light when the Experiment Quantity is reached:**</u>

When the Marker (M4) is set, the Output (Y17) will be switched on.

Note: The Marker (M4) is used to turn on the Warning Light (Y17) this will be observed

by the operator who will take the necessary steps to begin a new experiment.

****
   Step 30
****

<u>**Resetting the Data Register values when the Experiments are complete:**</u>

When the Input (X26) is switched on, the Data Registers values (D0) to (D4) are reset to a

value of zero. The Marker (M4) will also be reset.

Note: At the beginning of a new experiment all Data Register values must obtain a value

of zero, by switching on and off the Toggle Switch (X26) this will be preformed. By

resetting the Marker (M4) the Warning Light will also be switched off.

****
   Step 37
****

<u>**Turning off the Vibratory Bowl:**</u>

When the Input (X24) is switched on, the Marker (M3) is set.

Note: The Toggle switch (X24) will be used to control the "On" position of the Vibration

Bowl Relay (Y7) via a Marker (M3).

****
   Step 39
****

<u>**Turning on the Vibratory Bowl Relay:**</u>

When the Marker (M3) comes on, the Output (Y7) will be switched on.

Note: Marker (M3) controls the Vibration Bowl Relay (Y7).

****
Step 41
****

Turning the Vibratory Bowl back On:

When the Input (X24) is switched off, the Marker (M3) will be is reset.

Note: The Toggle switch (X24) will be used to control the "Off" position of the Vibratory

Bowl Relay (Y7) by resetting the Marker (M3).

****
Step 43
****

End Program

Wiper Blade Trap

Angle 0^0

Experiment Height (mm)	No of Components Pass By C2	No of components Fall off. C8	Blockage Number C6	Performance Number C12
5.60	0	200	0	0
5.84	198	2	9	9
6.08	198	2	5	49
6.32	198	2	3	69
6.56	197	3	2	78.5
6.80	200	0	2	80
7.04	200	0	6	40
7.28	200	0	2	80
7.52	191	9	9	5.5
7.76	198	2	6	39
8.00	198	2	2	79
8.24	198	2	4	59
8.48	200	0	3	70
8.72	195	5	8	17.5
8.96	199	1	5	49.5
9.20	197	3	11	-11.5
9.44	198	2	6	39
9.68	198	2	6	39
9.92	198	2	5	49
10.16	200	0	0	100
10.40	199	1	8	19.5
10.64	197	3	8	18.5
10.88	199	1	3	69.5
11.12	199	1	3	69.5
11.36	199	1	4	59.5
11.60	198	2	7	29
11.84	197	3	6	38.5
12.08	199	1	2	79.5
12.32	196	4	1	88
12.56	198	2	4	59
12.80	192	8	3	66

Wiper Blade Trap

Angle 3.6^0

Experiment Height (mm)	No of Components Pass By C2	No of components Fall off. C8	Blockage Number C6	Performance Number C12
5.60	0	200	0	0
5.84	197	3	0	98.5
6.08	198	2	7	29
6.32	198	2	5	49
6.56	200	0	3	70
6.80	197	3	6	38.5
7.04	200	0	2	80
7.28	200	0	9	10
7.52	191	9	2	75.5
7.76	198	2	6	39
8.00	197	3	2	78.5
8.24	198	2	4	59
8.48	197	3	3	68.5
8.72	195	5	8	17.5
8.96	198	2	5	49
9.20	197	3	11	-11.5
9.44	196	4	6	38
9.68	198	2	0	99
9.92	197	3	5	48.5
10.16	200	0	8	20
10.40	199	1	8	19.5
10.64	197	3	3	68.5
10.88	199	1	4	59.5
11.12	198	2	3	69
11.36	197	3	4	58.5
11.60	199	1	7	29.5
11.84	198	2	6	39
12.08	199	1	2	79.5
12.32	197	3	1	88.5
12.56	198	2	4	59
12.80	195	5	3	67.5

Wiper Blade Trap

Angle 7.2^0

Experiment Height (mm)	No of Components Pass By C2	No of components Fall off. C8	Blockage Number C6	Performance Number C12
5.60	0	200	0	0
5.84	198	2	7	29
6.08	197	3	8	18.5
6.32	196	4	6	38
6.56	185	15	5	42.5
6.80	187	13	9	3.5
7.04	190	10	2	75
7.28	193	7	3	66.5
7.52	191	9	5	45.5
7.76	187	13	7	23.5
8.00	186	14	2	73
8.24	189	11	3	64.5
8.48	187	13	4	53.5
8.72	185	15	6	32.5
8.96	183	17	7	21.5
9.20	188	12	4	54
9.44	187	13	2	73.5
9.68	191	9	1	85.5
9.92	194	6	9	7
10.16	193	7	6	36.5
10.40	191	9	7	25.5
10.64	189	11	3	64.5
10.88	188	12	2	74
11.12	187	13	5	43.5
11.36	191	9	3	65.5
11.60	193	7	4	56.5
11.84	192	8	6	36
12.08	191	9	3	65.5
12.32	189	11	4	54.5
12.56	190	10	2	75
12.80	191	9	5	45.5

Wiper Blade Trap

Angle 10.8⁰

Experiment Height (mm)	No of Components Pass By C2	No of components Fall off. C8	Blockage Number C6	Performance Number C12
5.60	0	200	0	0
5.84	167	33	10	-16.5
6.08	164	36	2	62
6.32	145	55	3	42.5
6.56	148	52	16	-86
6.80	172	28	11	-24
7.04	169	31	9	-5.5
7.28	175	25	17	-82.5
7.52	164	36	14	-58
7.76	159	41	8	-0.5
8.00	157	43	12	-41.5
8.24	163	37	12	-38.5
8.48	165	35	11	-27.5
8.72	169	31	9	-5.5
8.96	159	41	8	-0.5
9.20	157	43	7	8.5
9.44	163	37	6	21.5
9.68	169	31	10	-15.5
9.92	157	43	8	-1.5
10.16	163	37	12	-38.5
10.40	170	30	14	-55
10.64	164	36	7	12
10.88	168	32	6	24
11.12	173	27	8	6.5
11.36	179	21	10	-10.5
11.60	172	28	12	-34
11.84	184	16	3	62
12.08	196	4	5	48
12.32	195	5	6	37.5
12.56	197	3	4	58.5
12.80	198	2	7	29

Wiper Blade Trap

Angle 14.4^0

Experiment Height (mm)	No of Components Pass By C2	No of components Fall off. C8	Blockage Number C6	Performance Number C12
5.60	0	200	0	0
5.84	131	69	12	-54.5
6.08	164	36	1	72
6.32	140	60	4	30
6.56	148	52	16	-86
6.80	179	21	6	29.5
7.04	177	23	9	-1.5
7.28	180	20	3	60
7.52	164	36	15	-68
7.76	169	31	7	14.5
8.00	172	28	17	-84
8.24	187	13	3	63.5
8.48	178	22	4	49
8.72	195	5	6	37.5
8.96	160	40	4	40
9.20	187	13	8	13.5
9.44	194	6	2	77
9.68	170	30	8	5
9.92	196	4	1	88
10.16	184	16	12	-28
10.40	185	15	6	32.5
10.64	176	24	8	8
10.88	163	37	8	1.5
11.12	184	16	7	22
11.36	198	2	4	59
11.60	172	28	10	-14
11.84	176	24	6	28
12.08	196	4	2	78
12.32	190	10	7	25
12.56	195	5	5	47.5
12.80	197	3	7	28.5

Wiper Blade Trap

Angle 18⁰

Experiment Height (mm)	No of Components Pass By C2	No of components Fall off. C8	Blockage Number C6	Performance Number C12
5.60	0	200	0	0
5.84	149	51	4	34.5
6.08	177	23	8	8.5
6.32	176	24	8	8
6.56	164	36	10	-18
6.80	155	45	9	-12.5
7.04	157	43	8	-1.5
7.28	163	37	5	31.5
7.52	172	28	10	-14
7.76	174	26	8	7
8.00	179	21	5	39.5
8.24	160	40	9	-10
8.48	171	29	7	15.5
8.72	164	36	8	2
8.96	173	27	7	16.5
9.20	162	38	5	31
9.44	177	23	10	-11.5
9.68	167	33	9	-6.5
9.92	164	36	4	42
10.16	169	31	6	24.5
10.40	154	46	10	-23
10.64	153	47	9	-13.5
10.88	162	38	8	1
11.12	151	49	4	35.5
11.36	172	28	7	16
11.60	163	37	8	1.5
11.84	198	2	2	79
12.08	196	4	3	68
12.32	198	2	1	89
12.56	197	3	3	68.5
12.80	198	2	2	79

Wiper Blade Trap

Angle 21.6⁰

Experiment Height (mm)	No of Components Pass By C2	No of components Fall off. C8	Blockage Number C6	Performance Number C12
5.60	0	200	0	0
5.84	153	47	5	26.5
6.08	148	52	10	-26
6.32	149	51	11	-35.5
6.56	158	42	9	-11
6.80	142	58	8	-9
7.04	145	55	5	22.5
7.28	152	48	7	6
7.52	151	49	10	-24.5
7.76	153	47	8	-3.5
8.00	149	51	6	14.5
8.24	147	53	9	-16.5
8.48	148	52	12	-46
8.72	152	48	7	6
8.96	143	57	5	21.5
9.20	139	61	6	9.5
9.44	142	58	10	-29
9.68	138	62	3	39
9.92	136	64	5	18
10.16	142	58	9	-19
10.40	151	49	2	55.5
10.64	146	54	6	13
10.88	148	52	4	34
11.12	143	57	8	-8.5
11.36	151	49	7	5.5
11.60	149	51	5	24.5
11.84	197	3	1	88.5
12.08	198	2	4	59
12.32	196	4	2	78
12.56	194	6	3	67
12.80	197	3	2	78.5

Wiper Blade Trap

Angle 25.2^0

Experiment Height (mm)	No of Components Pass By C2	No of components Fall off. C8	Blockage Number C6	Performance Number C12
5.60	0	200	0	0
5.84	143	57	4	31.5
6.08	159	41	10	-20.5
6.32	148	52	8	-6
6.56	130	70	7	-5
6.80	163	37	2	61.5
7.04	142	58	4	31
7.28	144	56	2	52
7.52	180	20	5	40
7.76	140	60	5	20
8.00	113	87	10	-43.5
8.24	154	46	8	-3
8.48	132	68	4	26
8.72	161	39	6	20.5
8.96	159	41	2	59.5
9.20	148	52	3	44
9.44	132	68	2	46
9.68	151	49	6	15.5
9.92	130	70	10	-35
10.16	162	38	8	1
10.40	170	30	7	15
10.64	132	68	5	16
10.88	154	46	8	-3
11.12	129	71	9	-25.5
11.36	141	59	7	0.5
11.60	127	73	4	23.5
11.84	198	2	4	59
12.08	199	1	3	69.5
12.32	196	4	2	78
12.56	198	2	3	69
12.80	194	6	1	87

Wiper Blade Trap

Angle 28.8^0

Experiment Height (mm)	No of Components Pass By C2	No of components Fall off. C8	Blockage Number C6	Performance Number C12
5.60	0	200	0	0
5.84	155	45	1	67.5
6.08	132	68	6	6
6.32	155	45	0	77.5
6.56	156	44	0	78
6.80	129	71	6	4.5
7.04	139	61	6	9.5
7.28	133	67	1	56.5
7.52	164	36	5	32
7.76	136	64	5	18
8.00	136	64	4	28
8.24	137	63	4	28.5
8.48	143	57	1	61.5
8.72	127	73	8	-16.5
8.96	165	35	0	82.5
9.20	149	51	1	64.5
9.44	153	47	1	66.5
9.68	152	48	6	16
9.92	152	48	4	36
10.16	154	46	3	47
10.40	151	49	3	45.5
10.64	157	43	0	78.5
10.88	147	53	2	53.5
11.12	153	47	1	66.5
11.36	152	48	1	66
11.60	156	44	3	48
11.84	192	8	10	-4
12.08	199	1	1	89.5
12.32	196	4	3	68
12.56	198	2	2	79
12.80	196	4	2	78

Wiper Blade Trap

Angle 32.4^0

Experiment Height (mm)	No of Components Pass By C2	No of components Fall off. C8	Blockage Number C6	Performance Number C12
5.60	0	200	0	0
5.84	143	57	2	51.5
6.08	155	45	2	57.5
6.32	152	48	2	56
6.56	136	64	6	8
6.80	151	49	7	5.5
7.04	144	56	2	52
7.28	144	56	6	12
7.52	145	55	2	52.5
7.76	154	46	2	57
8.00	139	61	4	29.5
8.24	144	56	3	42
8.48	156	44	6	18
8.72	161	39	2	60.5
8.96	155	45	0	77.5
9.20	147	53	4	33.5
9.44	156	44	3	48
9.68	152	48	5	26
9.92	149	51	2	54.5
10.16	163	37	6	21.5
10.40	159	41	5	29.5
10.64	162	38	4	41
10.88	155	45	3	47.5
11.12	144	56	4	32
11.36	156	44	7	8
11.60	157	43	6	18.5
11.84	194	6	0	97
12.08	197	3	0	98.5
12.32	198	2	0	99
12.56	198	2	0	99
12.80	197	2	0	98.5

<u>Wiper Blade Trap</u>

Angle 36⁰

Experiment Height (mm)	No of Components Pass By C2	No of components Fall off. C8	Blockage Number C6	Performance Number C12
5.60	0	200	0	0
5.84	160	40	0	80
6.08	154	46	2	57
6.32	132	68	2	46
6.56	145	55	2	52.5
6.80	153	47	1	66.5
7.04	119	81	4	19.5
7.28	124	76	3	32
7.52	138	62	1	59
7.76	121	79	4	20.5
8.00	132	68	3	36
8.24	151	49	2	55.5
8.48	145	55	0	72.5
8.72	127	73	2	43.5
8.96	143	57	3	41.5
9.20	125	75	1	52.5
9.44	137	63	2	48.5
9.68	139	61	3	39.5
9.92	129	71	5	14.5
10.16	134	66	2	47
10.40	151	49	1	65.5
10.64	132	68	0	66
10.88	157	43	3	48.5
11.12	154	46	2	57
11.36	137	63	1	58.5
11.60	142	58	3	41
11.84	198	2	0	99
12.08	197	3	1	88.5
12.32	199	1	2	79.5
12.56	195	5	0	97.5
12.80	194	6	3	67

Wiper Blade Trap

Angle 39.6^0

Experiment Height (mm)	No of Components Pass By C2	No of components Fall off. C8	Blockage Number C6	Performance Number C12
5.60	0	200	0	0
5.84	136	64	3	38
6.08	146	54	1	63
6.32	153	47	0	76.5
6.56	145	55	0	72.5
6.80	138	62	2	49
7.04	144	56	1	62
7.28	145	55	1	62.5
7.52	140	60	0	70
7.76	155	45	2	57.5
8.00	137	63	0	68.5
8.24	147	53	0	73.5
8.48	147	53	0	73.5
8.72	143	57	1	61.5
8.96	151	49	0	75.5
9.20	146	54	2	53
9.44	143	57	1	61.5
9.68	138	62	0	69
9.92	151	49	1	65.5
10.16	140	60	1	60
10.40	137	63	0	68.5
10.64	145	55	2	52.5
10.88	135	65	0	67.5
11.12	140	60	0	70
11.36	143	57	1	61.5
11.60	151	49	2	55.5
11.84	197	3	3	68.5
12.08	196	4	2	78
12.32	198	2	0	99
12.56	193	7	1	86.5
12.80	198	2	0	99

Wiper Blade Trap

Angle 43.2^0

Experiment Height (mm)	No of Components Pass By C2	No of components Fall off. C8	Blockage Number C6	Performance Number C12
5.60	0	200	0	0
5.84	146	54	0	73
6.08	151	49	0	75.5
6.32	152	48	0	76
6.56	157	43	0	78.5
6.80	147	53	0	73.5
7.04	154	46	0	77
7.28	156	44	1	68
7.52	147	53	0	73.5
7.76	149	51	0	74.5
8.00	148	52	0	74
8.24	152	48	0	76
8.48	151	49	0	75.5
8.72	145	55	0	72.5
8.96	145	55	2	52.5
9.20	150	50	1	65
9.44	148	52	0	74
9.68	155	45	0	77.5
9.92	152	48	0	76
10.16	151	49	0	75.5
10.40	148	52	0	74
10.64	149	51	1	64.5
10.88	152	48	1	66
11.12	153	47	0	76.5
11.36	145	55	1	62.5
11.60	160	40	3	50
11.84	190	10	0	95
12.08	197	3	0	98.5
12.32	197	3	0	98.5
12.56	194	6	0	97
12.80	196	4	0	98

Wiper Blade Trap

Angle 46.8^0

Experiment Height (mm)	No of Components Pass By C2	No of components Fall off. C8	Blockage Number C6	Performance Number C12
5.60	0	200	0	0
5.84	154	46	1	67
6.08	149	51	0	74.5
6.32	150	50	1	65
6.56	131	69	0	65.5
6.80	150	50	0	75
7.04	149	51	2	54.5
7.28	155	45	0	77.5
7.52	151	49	0	75.5
7.76	142	58	0	71
8.00	156	44	1	68
8.24	139	61	2	49.5
8.48	154	46	0	77
8.72	145	55	1	62.5
8.96	155	45	0	77.5
9.20	153	47	0	76.5
9.44	156	44	0	78
9.68	152	48	0	76
9.92	148	52	0	74
10.16	147	53	0	73.5
10.40	147	53	0	73.5
10.64	156	44	0	78
10.88	145	55	1	62.5
11.12	156	44	0	78
11.36	153	47	0	76.5
11.60	158	42	2	59
11.84	198	2	0	99
12.08	199	1	0	99.5
12.32	197	3	0	98.5
12.56	198	2	0	99
12.80	199	1	0	99.5

Wiper Blade Trap

Angle 50.4^0

Experiment Height (mm)	No of Components Pass By C2	No of components Fall off. C8	Blockage Number C6	Performance Number C12
5.60	0	200	0	0
5.84	146	54	0	73
6.08	149	51	0	74.5
6.32	146	54	0	73
6.56	142	58	0	71
6.80	150	50	0	75
7.04	146	54	0	73
7.28	144	56	0	72
7.52	147	53	0	73.5
7.76	143	57	0	71.5
8.00	143	57	0	71.5
8.24	152	48	1	66
8.48	138	62	0	69
8.72	148	52	0	74
8.96	149	51	0	74.5
9.20	143	57	1	61.5
9.44	151	49	0	75.5
9.68	142	58	1	61
9.92	146	54	0	73
10.16	149	51	0	74.5
10.40	149	51	0	74.5
10.64	142	58	0	71
10.88	142	58	0	71
11.12	150	50	0	75
11.36	149	51	0	74.5
11.60	152	48	0	76
11.84	197	3	1	88.5
12.08	194	6	0	97
12.32	199	1	1	89.5
12.56	196	4	0	98
12.80	198	2	0	99

Wiper Blade Trap

Angle 54^0

Experiment Height (mm)	No of Components Pass By C2	No of components Fall off. C8	Blockage Number C6	Performance Number C12
5.60	0	200	0	0
5.84	148	52	0	74
6.08	152	48	0	76
6.32	148	52	3	44
6.56	153	47	0	76.5
6.80	150	50	0	75
7.04	154	46	0	77
7.28	150	50	0	75
7.52	147	53	0	73.5
7.76	147	53	0	73.5
8.00	151	49	0	75.5
8.24	151	49	1	65.5
8.48	152	48	0	76
8.72	148	52	0	74
8.96	146	54	0	73
9.20	149	51	0	74.5
9.44	151	49	0	75.5
9.68	149	51	0	74.5
9.92	157	43	0	78.5
10.16	153	47	0	76.5
10.40	149	51	1	64.5
10.64	156	44	0	78
10.88	145	55	0	72.5
11.12	151	49	2	55.5
11.36	150	50	0	75
11.60	148	52	0	74
11.84	198	2	1	89
12.08	196	4	0	98
12.32	192	8	2	76
12.56	199	1	1	89.5
12.80	197	3	0	98.5

Wiper Blade Trap

Angle 57.6^0

Experiment Height (mm)	No of Components Pass By C2	No of components Fall off. C8	Blockage Number C6	Performance Number C12
5.60	0	200	0	0
5.84	129	71	2	48.5
6.08	122	78	0	61
6.32	152	48	0	76
6.56	149	51	0	74.5
6.80	154	46	0	77
7.04	156	44	0	78
7.28	148	52	0	74
7.52	153	47	0	76.5
7.76	151	49	0	75.5
8.00	147	53	0	73.5
8.24	152	48	0	76
8.48	149	51	0	74.5
8.72	147	53	1	63.5
8.96	148	52	2	54
9.20	152	48	0	76
9.44	151	49	0	75.5
9.68	152	48	1	66
9.92	148	52	0	74
10.16	153	47	0	76.5
10.40	149	51	0	74.5
10.64	149	51	0	74.5
10.88	152	48	0	76
11.12	146	54	0	73
11.36	154	46	0	77
11.60	153	47	0	76.5
11.84	135	65	1	57.5
12.08	200	0	0	100
12.32	199	1	1	89.5
12.56	200	0	0	100
12.80	198	2	0	99

Wiper Blade Trap

Angle 61.2^0

Experiment Height (mm)	No of Components Pass By C2	No of components Fall off. C8	Blockage Number C6	Performance Number C12
5.60	0	200	0	0
5.84	152	48	0	76
6.08	162	38	0	81
6.32	169	31	0	84.5
6.56	174	26	0	87
6.80	173	27	0	86.5
7.04	149	51	0	74.5
7.28	148	52	0	74
7.52	157	43	1	68.5
7.76	142	58	0	71
8.00	157	43	0	78.5
8.24	151	49	0	75.5
8.48	151	49	1	65.5
8.72	158	42	0	79
8.96	161	39	0	80.5
9.20	163	37	0	81.5
9.44	164	36	1	72
9.68	168	32	0	84
9.92	155	45	1	67.5
10.16	152	48	0	76
10.40	153	47	0	76.5
10.64	165	35	0	82.5
10.88	161	39	0	80.5
11.12	159	41	1	69.5
11.36	161	39	1	70.5
11.60	163	37	2	61.5
11.84	198	2	0	99
12.08	199	1	0	99.5
12.32	196	4	1	88
12.56	195	5	0	97.5
12.80	198	2	0	99

Wiper Blade Trap

Angle 64.8⁰

Experiment Height (mm)	No of Components Pass By C2	No of components Fall off. C8	Blockage Number C6	Performance Number C12
5.60	0	200	0	0
5.84	146	54	1	63
6.08	157	43	1	68.5
6.32	149	51	0	74.5
6.56	151	49	0	75.5
6.80	150	50	0	75
7.04	149	51	0	74.5
7.28	154	46	0	77
7.52	156	44	0	78
7.76	152	48	0	76
8.00	156	44	0	78
8.24	152	48	0	76
8.48	157	43	1	68.5
8.72	155	45	0	77.5
8.96	149	51	0	74.5
9.20	150	50	0	75
9.44	151	49	0	75.5
9.68	147	53	0	73.5
9.92	153	47	1	66.5
10.16	157	43	0	78.5
10.40	155	45	2	57.5
10.64	151	49	0	75.5
10.88	148	52	0	74
11.12	149	51	1	64.5
11.36	151	49	0	75.5
11.60	153	47	1	66.5
11.84	198	2	0	99
12.08	192	8	0	96
12.32	197	3	0	98.5
12.56	195	5	1	87.5

Wiper Blade Trap

Angle 68.4^0

Experiment Height (mm)	No of Components Pass By C2	No of components Fall off. C8	Blockage Number C6	Performance Number C12
5.60	0	200	0	0
5.84	154	46	0	77
6.08	157	43	1	68.5
6.32	162	38	0	81
6.56	153	47	0	76.5
6.80	147	53	0	73.5
7.04	152	48	0	76
7.28	148	52	1	64
7.52	152	48	0	76
7.76	149	51	0	74.5
8.00	157	43	2	58.5
8.24	155	45	0	77.5
8.48	162	38	0	81
8.72	171	29	1	75.5
8.96	169	31	0	84.5
9.20	159	41	0	79.5
9.44	158	42	0	79
9.68	154	46	0	77
9.92	153	47	1	66.5
10.16	152	48	0	76
10.40	147	53	0	73.5
10.64	148	52	0	74
10.88	146	54	0	73
11.12	151	49	0	75.5
11.36	147	53	0	73.5
11.60	145	55	1	62.5
11.84	198	2	0	99
12.08	196	4	1	88
12.32	197	3	0	98.5
12.56	192	8	0	96
12.80	195	5	1	87.5

Wiper Blade Trap

Angle 72^0

Experiment Height (mm)	No of Components Pass By C2	No of components Fall off. C8	Blockage Number C6	Performance Number C12
5.60	0	200	0	0
5.84	172	28	0	86
6.08	143	57	2	51.5
6.32	154	46	1	67
6.56	161	39	1	70.5
6.80	152	48	0	76
7.04	156	44	0	78
7.28	156	44	1	68
7.52	149	51	0	74.5
7.76	154	46	1	67
8.00	155	45	0	77.5
8.24	156	44	2	58
8.48	149	51	0	74.5
8.72	153	47	1	66.5
8.96	152	48	2	56
9.20	155	45	1	67.5
9.44	149	51	0	74.5
9.68	148	52	0	74
9.92	156	44	1	68
10.16	154	46	0	77
10.40	153	47	0	76.5
10.64	149	51	1	64.5
10.88	151	49	0	75.5
11.12	156	44	2	58
11.36	154	46	1	67
11.60	156	44	2	58
11.84	197	3	1	88.5
12.08	198	2	0	99
12.32	196	4	1	88
12.56	199	1	0	99.5
12.80	197	3	1	88.5

Wiper Blade Trap

Angle 75.6⁰

Experiment Height (mm)	No of Components Pass By C2	No of components Fall off. C8	Blockage Number C6	Performance Number C12
5.60	0	200	0	0
5.84	154	46	0	77
6.08	153	47	0	76.5
6.32	155	45	2	57.5
6.56	157	43	0	78.5
6.80	161	39	0	80.5
7.04	159	41	2	59.5
7.28	163	37	1	71.5
7.52	154	46	2	57
7.76	151	49	0	75.5
8.00	152	48	1	66
8.24	150	50	0	75
8.48	155	45	2	57.5
8.72	161	39	1	70.5
8.96	163	37	1	71.5
9.20	162	38	2	61
9.44	160	40	0	80
9.68	159	41	1	69.5
9.92	153	47	0	76.5
10.16	154	46	0	77
10.40	152	48	2	56
10.64	151	49	0	75.5
10.88	152	48	0	76
11.12	157	43	0	78.5
11.36	158	42	1	69
11.60	159	41	2	59.5
11.84	197	3	3	68.5
12.08	195	5	2	77.5
12.32	198	2	1	89
12.56	199	1	0	99.5
12.80	197	3	1	88.5

Wiper Blade Trap

Angle 79.2⁰

Experiment Height (mm)	No of Components Pass By C2	No of components Fall off. C8	Blockage Number C6	Performance Number C12
5.60	0	200	0	0
5.84	164	36	2	62
6.08	154	46	1	67
6.32	143	57	3	41.5
6.56	172	28	0	86
6.80	156	44	2	58
7.04	152	48	3	46
7.28	154	46	2	57
7.52	156	44	1	68
7.76	153	47	0	76.5
8.00	149	51	3	44.5
8.24	155	45	4	37.5
8.48	149	51	2	54.5
8.72	148	52	1	64
8.96	156	44	0	78
9.20	149	51	4	34.5
9.44	156	44	5	28
9.68	154	46	0	77
9.92	157	43	2	58.5
10.16	161	39	4	40.5
10.40	149	51	3	44.5
10.64	148	52	5	24
10.88	153	47	2	56.5
11.12	152	48	3	46
11.36	157	43	5	28.5
11.60	161	39	4	40.5
11.84	198	2	0	99
12.08	197	3	1	88.5
12.32	196	4	1	88
12.56	198	2	0	99
12.80	197	3	2	78.5

Wiper Blade Trap

Angle 82.8^0

Experiment Height (mm)	No of Components Pass By C2	No of components Fall off. C8	Blockage Number C6	Performance Number C12
5.60	0	200	0	0
5.84	195	5	0	97.5
6.08	194	6	0	97
6.32	187	13	0	93.5
6.56	193	7	1	86.5
6.80	195	5	0	97.5
7.04	196	4	0	98
7.28	194	6	0	97
7.52	192	8	1	86
7.76	191	9	0	95.5
8.00	194	6	0	97
8.24	196	4	2	78
8.48	195	5	0	97.5
8.72	193	7	0	96.5
8.96	192	8	2	76
9.20	190	10	0	95
9.44	189	11	1	84.5
9.68	191	9	0	95.5
9.92	187	13	0	93.5
10.16	193	7	0	96.5
10.40	194	6	1	87
10.64	196	4	0	98
10.88	191	9	0	95.5
11.12	187	13	1	83.5
11.36	186	14	0	93
11.60	191	9	1	85.5
11.84	199	1	2	79.5
12.08	198	2	1	89
12.32	196	4	0	98
12.56	197	3	0	98.5
12.80	195	5	1	87.5

Wiper Blade Trap

Angle 86.4^0

Experiment Height (mm)	No of Components Pass By C2	No of components Fall off. C8	Blockage Number C6	Performance Number C12
5.60	0	200	0	0
5.84	193	7	0	96.5
6.08	197	3	0	98.5
6.32	185	15	0	92.5
6.56	195	5	0	97.5
6.80	194	6	0	97
7.04	195	5	0	97.5
7.28	196	4	1	88
7.52	194	6	0	97
7.76	197	3	0	98.5
8.00	198	2	0	99
8.24	199	1	0	99.5
8.48	196	4	0	98
8.72	194	6	0	97
8.96	195	5	0	97.5
9.20	193	7	0	96.5
9.44	192	8	0	96
9.68	192	8	0	96
9.92	194	6	1	87
10.16	197	3	0	98.5
10.40	194	6	0	97
10.64	193	7	2	76.5
10.88	192	8	0	96
11.12	194	6	0	97
11.36	198	2	0	99
11.60	199	1	0	99.5
11.84	197	3	0	98.5
12.08	199	1	0	99.5
12.32	197	3	0	98.5
12.56	196	4	0	98
12.80	192	8	0	96

Wiper Blade Trap

Angle 90⁰

Experiment Height (mm)	No of Components Pass By C2	No of components Fall off. C8	Blockage Number C6	Performance Number C12
5.60	0	200	0	0
5.84	200	0	0	100
6.08	199	1	0	99.5
6.32	200	0	0	100
6.56	197	3	0	98.5
6.80	196	4	0	98
7.04	194	6	1	87
7.28	200	0	0	100
7.52	198	2	0	99
7.76	199	1	1	89.5
8.00	198	2	0	99
8.24	199	1	0	99.5
8.48	197	3	0	98.5
8.72	198	2	0	99
8.96	199	1	0	99.5
9.20	200	0	1	90
9.44	198	2	0	99
9.68	197	3	1	88.5
9.92	196	4	0	98
10.16	195	5	1	87.5
10.40	194	6	0	97
10.64	199	1	0	99.5
10.88	200	0	1	90
11.12	199	1	0	99.5
11.36	198	2	0	99
11.60	198	2	0	99
11.84	200	0	0	100
12.08	200	0	1	90
12.32	199	1	0	99.5
12.56	200	0	1	90
12.80	200	0	1	90

Height (mm)	Ang 0	Ang 3.6	Ang 7.2	Ang 10.8	Ang 14.4	Ang 18	Ang 21.6	Ang 25.2	Ang 28.8	Ang 32.4	Ang 36	Ang 39.6	Ang 43.2	Ang 46.8	Ang 50.4	Ang 54	Ang 57.6	Ang 61.2	Ang 64.8	Ang 68.4	Ang 72	Ang 75.6	Ang 79.2	Ang 82.8	Ang 86.4	Ang 90
5.60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5.84	9	98.5	29	-16.5	-55	35	27	31.5	67.5	51.5	80	38	73	67	73	74	-21.5	76	63	77	86	77	62	97.5	96.5	100
6.08	49	29	18.5	62	72	8.5	-26	-21	6	57.5	57	63	75.5	74.5	74.5	76	61	81	68.5	68.5	51.5	76.5	67	97	98.5	99.5
6.32	69	49	38	42.5	30	8	-36	-6	77.5	56	46	76.5	76	65	73	44	76	84.5	74.5	81	67	57.5	41.5	93.5	92.5	100
6.56	78.5	70	42.5	-86	-86	-18	-11	-5	78	8	52.5	72.5	78.5	65.5	71	76.5	74.5	87	75.5	76.5	70.5	78.5	86	86.5	97.5	98.5
6.80	80	38.5	3.5	-24	30	-13	-9	61.5	4.5	5.5	66.5	49	73.5	75	75	75	77	86.5	75	73.5	76	80.5	58	97.5	97	98
7.04	40	80	75	-5.5	-1.5	-1.5	23	31	9.5	52	19.5	62	77	54.5	73	77	78	74.5	74.5	76	78	59.5	46	98	97.5	87
7.28	80	10	66.5	-82.5	60	32	6	52	56.5	12	32	62.5	68	77.5	72	75	74	74	77	64	68	71.5	57	97	88	100
7.52	5.5	75.5	45.5	-58	-68	-14	-25	40	32	52.5	59	70	73.5	75.5	73.5	73.5	76.5	68.5	78	76	74.5	57	68	86	97	99
7.76	39	39	23.5	-0.5	15	7	-3.5	20	18	57	20.5	57.5	74.5	71	71.5	73.5	75.5	71	76	74.5	67	75.5	76.5	95.5	98.5	89.5
8.00	79	78.5	73	-41.5	-84	40	15	-44	28	29.5	36	68.5	74	68	71.5	75.5	73.5	78.5	78	58.5	77.5	66	44.5	97	99	99
8.24	59	59	64.5	-38.5	64	-10	-17	-3	28.5	42	55.5	73.5	76	49.5	66	65.5	76	75.5	76	77.5	58	75	37.5	78	99.5	99.5
8.48	70	68.5	53.5	-27.5	49	16	-46	26	61.5	18	72.5	73.5	75.5	77	69	76	74.5	65.5	68.5	81	74.5	57.5	54.5	97.5	98	98.5
8.72	17.5	17.5	32.5	-5.5	38	2	6	20.5	-17	60.5	43.5	61.5	72.5	62.5	74	74	63.5	79	77.5	75.5	66.5	70.5	64	96.5	97	99
8.96	49.5	49	21.5	-0.5	40	17	22	59.5	82.5	77.5	41.5	75.5	52.5	77.5	74.5	73	54	80.5	74.5	84.5	56	71.5	78	76	97.5	99.5
9.20	-11.5	-12	54	8.5	14	31	9.5	44	64.5	33.5	52.5	53	65	76.5	61.5	74.5	76	81.5	75	79.5	67.5	61	34.5	95	96.5	90
9.44	39	38	73.5	21.5	77	-12	-29	46	66.5	48	48.5	61.5	74	78	75.5	75.5	75.5	72	75.5	79	74.5	80	28	84.5	96	99
9.68	39	99	85.5	-15.5	5	-6.5	39	15.5	16	26	39.5	69	77.5	76	61	74.5	66	84	73.5	77	74	69.5	77	95.5	96	88.5
9.92	49	48.5	7	-1.5	88	42	18	-35	36	54.5	14.5	65.5	76	74	73	78.5	74	67.5	66.5	66.5	68	76.5	58.5	93.5	87	98
10.16	100	20	36.5	-38.5	-28	25	-19	1	47	21.5	47	60	75.5	73.5	74.5	76.5	76.5	76	78.5	76	77	77	40.5	96.5	98.5	87.5
10.40	19.5	19.5	25.5	-55	33	-23	56	15	45.5	29.5	65.5	68.5	74	73.5	74.5	64.5	74.5	76.5	57.5	73.5	76.5	56	44.5	87	97	97
10.64	18.5	68.5	64.5	12	8	-14	13	16	78.5	41	66	52.5	64.5	78	71	78	74.5	82.5	75.5	74	64.5	75.5	24	98	76.5	99.5
10.88	69.5	59.5	74	24	1.5	1	34	-3	53.5	47.5	48.5	67.5	66	62.5	71	72.5	76	80.5	74	73	75.5	76	56.5	95.5	96	90
11.12	69.5	69	43.5	6.5	22	36	-8.5	-26	66.5	32	57	70	76.5	78	75	55.5	73	69.5	64.5	75.5	58	78.5	46	83.5	97	99.5
11.36	59.5	58.5	65.5	-10.5	59	16	5.5	0.5	66	8	58.5	61.5	62.5	76.5	74.5	75	77	70.5	75.5	73.5	67	69	28.5	93	99	99
11.60	29	29.5	56.5	-34	-14	1.5	25	23.5	48	18.5	41	55.5	50	59	76	74	76.5	61.5	66.5	62.5	58	59.5	40.5	85.5	99.5	99

Wiper Blade Tool

Angle 43.2⁰

Experiment Height (mm)	No of Components Pass By C2	No of components Fall off. C8	Blockage Number C6	Performance Number C12
5.60	0	1000	0	0
5.84	820	180	3.0	76
6.08	780	220	2.0	74
6.32	830	170	3.0	77
6.56	830	170	2.0	79
6.80	820	180	4.0	74
7.04	840	160	3.0	78
7.28	883	117	6.0	76.3
7.52	858	142	6.0	73.8
7.76	788	212	2.0	74.8
8.00	788	212	3.0	72.8
8.24	843	157	4.0	76.3
8.48	898	102	7.0	75.8
8.72	758	242	1.0	73.8
8.96	923	77	9.0	74.3
9.20	820	180	4.0	74
9.44	865	135	6.0	74.5
9.68	885	115	5.0	78.5
9.92	885	115	6.0	76.5
10.16	920	80	8.0	76
10.40	785	215	2.0	74.5
10.64	850	150	6.0	73
10.88	825	175	4.0	74.5
11.12	870	130	5.0	77
11.36	845	155	6.0	72.5
11.60	880	120	7.0	74

Wiper Blade Trap

Angle 46.8^0

Experiment Height (mm)	No of Components Pass By C2	No of components Fall off. C8	Blockage Number C6	Performance Number C12
5.60	0	1000	0	0
5.84	830	170	4	75
6.08	765	235	2	72.5
6.32	810	190	3	75
6.56	740	260	1	72
6.80	790	210	2	75
7.04	785	215	3	72.5
7.28	815	185	2	77.5
7.52	835	165	5	73.5
7.76	850	150	6	73
8.00	780	220	3	72
8.24	795	205	5	69.5
8.48	850	150	4	77
8.72	725	275	1	70.5
8.96	835	165	3	77.5
9.20	845	155	5	74.5
9.44	840	160	3	78
9.68	780	220	2	74
9.92	840	160	5	74
10.16	850	150	5	75
10.40	805	195	3	74.5
10.64	940	60	8	78
10.88	805	195	5	70.5
11.12	800	200	3	74
11.36	805	195	4	72.5
11.60	910	90	7	77

Wiper Blade Trap

Angle 50.4^0

Experiment Height (mm)	No of Components Pass By C2	No of components Fall off. C8	Blockage Number C6	Performance Number C12
5.60	0	1000	0	0
5.84	810	190	4	73
6.08	865	135	6	74.5
6.32	770	230	2	73
6.56	845	155	7	70.5
6.80	850	150	6	73
7.04	790	210	3	73
7.28	800	200	4	72
7.52	835	165	5	73.5
7.76	775	225	3	71.5
8.00	755	245	2	71.5
8.24	800	200	3	74
8.48	740	260	2	70
8.72	820	180	4	74
8.96	805	195	3	74.5
9.20	775	225	4	69.5
9.44	875	125	6	75.5
9.68	770	230	4	69
9.92	830	170	5	73
10.16	865	135	6	74.5
10.40	805	195	3	74.5
10.64	790	210	4	71
10.88	850	150	7	71
11.12	910	90	8	75
11.36	845	155	5	74.5
11.60	820	180	3	76

Wiper Blade Trap

Angle 54⁰

Experiment Height (mm)	No of Components Pass By C2	No of components Fall off. C8	Blockage Number C6	Performance Number C12
5.60	0	1000	0	0
5.84	805	195	3	74.5
6.08	860	140	5	76
6.32	780	220	4	70
6.56	915	85	7	77.5
6.80	830	170	5	73
7.04	830	170	3	77
7.28	910	90	8	75
7.52	800	200	4	72
7.76	775	225	2	73.5
8.00	775	225	3	71.5
8.24	835	165	5	73.5
8.48	880	120	6	76
8.72	885	115	7	74.5
8.96	830	170	5	73
9.20	905	95	9	72.5
9.44	760	240	2	72
9.68	845	155	5	74.5
9.92	905	95	7	76.5
10.16	825	175	3	76.5
10.40	845	155	6	72.5
10.64	920	80	8	76
10.88	940	60	9	76
11.12	835	165	6	71.5
11.36	850	150	5	75

11.60	935	65	6	81.5

Wiper Blade Trap

Angle 57.6^0

Experiment Height (mm)	No of Components Pass By C2	No of components Fall off. C8	Blockage Number C6	Performance Number C12
5.60	0	1000	0	0
5.84	740	260	3	68
6.08	810	190	5	71
6.32	920	80	8	76
6.56	785	215	3	72.5
6.80	930	70	8	77
7.04	860	140	6	74
7.28	920	80	9	74
7.52	825	175	4	74.5
7.76	875	125	6	75.5
8.00	815	185	5	71.5
8.24	880	120	6	76
8.48	825	175	4	74.5
8.72	815	185	5	71.5
8.96	820	180	6	70
9.20	840	160	4	76
9.44	855	145	5	75.5
9.68	860	140	6	74
9.92	840	160	5	74
10.16	825	175	3	76.5
10.40	825	175	4	74.5
10.64	865	135	6	74.5
10.88	860	140	5	76
11.12	790	210	3	73
11.36	810	190	2	77
11.60	845	155	4	76.5

Wiper Blade Trap

Angle 61.2^0

Experiment Height (mm)	No of Components Pass By C2	No of components Fall off. C8	Blockage Number C6	Performance Number C12
5.60	0	1000	0	0
5.84	860	140	5	76
6.08	870	130	3	81
6.32	905	95	4	82.5
6.56	890	110	2	85
6.80	925	75	4	84.5
7.04	955	45	7	81.5
7.28	920	80	6	80
7.52	945	55	9	76.5
7.76	885	115	4	80.5
8.00	905	95	6	78.5
8.24	870	130	5	77
8.48	895	105	7	75.5
8.72	950	50	8	79
8.96	925	75	6	80.5
9.20	995	5	9	81.5
9.44	880	120	4	80
9.68	900	100	3	84
9.92	875	125	6	75.5
10.16	820	180	3	76
10.40	845	155	4	76.5
10.64	905	95	5	80.5
10.88	885	115	4	80.5
11.12	955	45	9	77.5
11.36	865	135	4	78.5

| 11.60 | 935 | 65 | 8 | 77.5 |

Wiper Blade Trap

Angle 64.8^0

Experiment Height (mm)	No of Components Pass By C2	No of components Fall off. C8	Blockage Number C6	Performance Number C12
5.60	0	1000	0	0
5.84	810	190	5	71
6.08	905	95	7	76.5
6.32	805	195	3	74.5
6.56	855	145	5	75.5
6.80	830	170	4	75
7.04	865	135	6	74.5
7.28	830	170	4	75
7.52	860	140	5	76
7.76	820	180	3	76
8.00	940	60	8	78
8.24	780	220	1	76
8.48	885	115	6	76.5
8.72	815	185	2	77.5
8.96	885	115	7	74.5
9.20	910	90	8	75
9.44	815	185	3	75.5
9.68	945	55	9	76.5
9.92	805	195	3	74.5
10.16	865	135	5	76.5
10.40	855	145	6	73.5
10.64	835	165	4	75.5
10.88	780	220	2	74
11.12	845	155	6	72.5
11.36	835	165	4	75.5

| 11.60 | 885 | 115 | 7 | 74.5 |

Wiper Blade Trap

Angle 68.4^0

Experiment Height (mm)	No of Components Pass By C2	No of components Fall off. C8	Blockage Number C6	Performance Number C12
5.60	0	1000	0	0
5.84	870	130	5	77
6.08	845	155	4	76.5
6.32	870	130	3	81
6.56	905	95	7	76.5
6.80	865	135	5	76.5
7.04	800	200	2	76
7.28	880	120	8	72
7.52	860	140	5	76
7.76	805	195	3	74.5
8.00	865	135	6	74.5
8.24	855	145	4	77.5
8.48	870	130	3	81
8.72	975	25	7	83.5
8.96	905	95	5	80.5
9.20	915	85	6	79.5
9.44	850	150	3	79
9.68	930	70	8	77
9.92	845	155	5	74.5
10.16	800	200	2	76
10.40	930	70	9	75
10.64	890	110	6	77
10.88	810	190	4	73
11.12	875	125	6	75.5
11.36	815	185	4	73.5

| **11.60** | 765 | 235 | 3 | 70.5 |

Wiper Blade Trap

Angle 72⁰

Experiment Height (mm)	No of Components Pass By C2	No of components Fall off. C8	Blockage Number C6	Performance Number C12
5.60	0	1000	0	0
5.84	870	130	4	79
6.08	845	155	6	72.5
6.32	910	90	8	75
6.56	825	175	2	78.5
6.80	860	140	5	76
7.04	900	100	6	78
7.28	820	180	3	76
7.52	845	155	5	74.5
7.76	790	210	2	75
8.00	935	65	8	77.5
8.24	860	140	6	74
8.48	845	155	5	74.5
8.72	905	95	8	74.5
8.96	800	200	4	72
9.20	935	65	9	75.5
9.44	825	175	4	74.5
9.68	840	160	5	74
9.92	880	120	6	76
10.16	910	90	7	77
10.40	805	195	2	76.5
10.64	745	255	1	72.5
10.88	815	185	3	75.5
11.12	820	180	4	74
11.36	870	130	6	75

| **11.60** | 880 | 120 | 7 | 74 |

Wiper Blade Trap

Angle 75.6^0

Experiment Height (mm)	No of Components Pass By C2	No of components Fall off. C8	Blockage Number C6	Performance Number C12
5.60	0	1000	0	0
5.84	850	150	4	77
6.08	885	115	6	76.5
6.32	915	85	9	73.5
6.56	825	175	2	78.5
6.80	945	55	8	78.5
7.04	815	185	3	75.5
7.28	935	65	7	79.5
7.52	810	190	4	73
7.76	915	85	8	75.5
8.00	800	200	3	74
8.24	930	70	9	75
8.48	775	225	2	73.5
8.72	845	155	3	78.5
8.96	895	105	5	79.5
9.20	810	190	2	77
9.44	920	80	7	78
9.68	855	145	4	77.5
9.92	945	55	9	76.5
10.16	830	170	3	77
10.40	840	160	6	72
10.64	855	145	5	75.5
10.88	820	180	3	76
11.12	945	55	8	78.5
11.36	810	190	2	77

| 11.60 | 895 | 105 | 7 | 75.5 |

WBT Experiment Results

Height (mm)	Angle 43.2	Angle 46.8	Angle 50.4	Angle 54	Angle 57.6	Angle 61.2	Angle 64.8	Angle 68.4	Angle 72	Angle 75.6
5.60	0	0	0	0	0	0	0	0	0	0
5.84	76	75	73	74.5	68	76	71	77	79	77
6.08	74	72.5	74.5	76	71	81	76.5	76.5	72.5	76.5
6.32	77	75	73	70	76	82.5	74.5	81	75	73.5
6.56	79	72	70.5	77.5	72.5	85	75.5	76.5	78.5	78.5
6.80	74	75	73	73	77	84.5	75	76.5	76	78.5
7.04	78	72.5	73	77	74	81.5	74.5	76	78	75.5
7.28	76.3	77.5	72	75	74	80	75	72	76	79.5
7.52	73.8	73.5	73.5	72	74.5	76.5	76	76	74.5	73
7.76	74.8	73	71.5	73.5	75.5	80.5	76	74.5	75	75.5
8.00	72.8	72	71.5	71.5	71.5	78.5	78	74.5	77.5	74
8.24	76.3	69.5	74	73.5	76	77	76	77.5	74	75
8.48	75.8	77	70	76	74.5	75.5	76.5	81	74.5	73.5
8.72	73.8	70.5	74	74.5	71.5	79	77.5	83.5	74.5	78.5
8.96	74.3	77.5	74.5	73	70	80.5	74.5	80.5	72	79.5
9.20	74	74.5	69.5	72.5	76	81.5	75	79.5	75.5	77
9.44	74.5	78	75.5	72	75.5	80	75.5	79	74.5	78
9.68	78.5	74	69	74.5	74	84	76.5	77	74	77.5
9.92	76.5	74	73	76.5	74	75.5	74.5	74.5	76	76.5
10.16	76	75	74.5	76.5	76.5	76	76.5	76	77	77
10.40	74.5	74.5	74.5	72.5	74.5	76.5	73.5	75	76.5	72
10.64	73	78	71	76	74.5	80.5	75.5	77	72.5	75.5
10.88	74.5	70.5	71	76	76	80.5	74	73	75.5	76
11.12	77	74	75	71.5	73	77.5	72.5	75.5	74	78.5
11.36	72.5	72.5	74.5	75	77	78.5	75.5	73.5	75	77
11.60	74	77	76	81.5	76.5	77.5	74.5	70.5	74	75.5

Raised Ledge Trap

Experiment Number	Experiment Angle (Deg)	No of Components Pass By Correctly Orientated	No of Components Fall Off At Raised Ledge	Performance %
1	4.000	27	473	5.4
2	4.138	45	455	9.0
3	4.276	30	470	6.0
4	4.414	35	465	7.0
5	4.552	27	473	5.4
6	4.690	28	472	5.6
7	4.828	43	457	8.6
8	4.966	50	450	10.0
9	5.104	30	470	6.0
10	5.242	20	480	4.0
11	5.380	35	465	7.0
12	5.518	40	460	8.0
13	5.656	80	420	16.0
14	5.794	159	341	31.8
15	5.932	182	318	36.4
16	6.070	215	285	43.0
17	6.208	404	96	80.8
18	6.346	415	85	83.0
19	6.484	468	32	93.6
20	6.622	481	19	96.2
21	6.760	491	9	98.2
22	6.898	500	0	100.0
23	7.036	500	0	100.0
24	7.174	500	0	100.0
25	7.312	500	0	100.0
26	7.450	498	2	99.6
27	7.588	500	0	100.0
28	7.726	500	0	100.0
29	7.864	500	0	100.0
30	8.002	500	0	100.0
31	8.140	500	0	100.0
32	8.278	500	0	100.0
33	8.416	497	3	99.4
34	8.554	500	0	100.0
35	8.692	498	2	99.6
36	8.830	500	0	100.0
37	8.968	500	0	100.0
38	9.106	500	0	100.0
39	9.244	500	0	100.0
40	9.382	500	0	100.0
41	9.520	500	0	100.0
42	9.658	500	0	100.0
43	9.796	476	24	95.2
44	9.934	350	150	70.0
45	10.072	120	380	24.0
46	10.210	125	375	25.0
47	10.348	85	415	17.0
48	10.486	50	450	10.0

Narrow Track Tool

Experiment Number	Experiment Distance (mm)	No of components Fall off	No of components Pass By	Orientation B	Orientation A	No of Components in Orientation (B) Not Falling Off	No of Components in Orientation (A) Falling Off	Performance No %
1	24.400	0	500	230	270	0	0	0.0
2	24.197	0	500	180	320	0	0	0.0
3	23.993	0	500	145	355	0	0	0.0
4	23.790	0	500	170	330	0	0	0.0
5	23.587	0	500	185	315	0	0	0.0
6	23.383	0	500	123	377	0	0	0.0
7	23.180	0	500	95	405	0	0	0.0
8	22.977	0	500	190	310	0	0	0.0
9	22.773	0	500	165	335	0	0	0.0
10	22.570	0	500	123	377	0	0	0.0
11	22.367	0	500	134	366	0	0	0.0
12	22.163	0	500	167	333	0	0	0.0
13	21.960	0	500	186	314	0	0	0.0
14	21.757	0	500	124	376	0	0	0.0
15	21.553	0	500	205	295	0	0	0.0
16	21.350	0	500	97	403	0	0	0.0
17	21.147	0	500	198	302	0	0	0.0
18	20.943	0	500	173	327	0	0	0.0
19	20.740	0	500	190	310	0	0	0.0
20	20.537	0	500	175	325	0	0	0.0
21	20.333	0	500	220	280	0	0	0.0
22	20.130	0	500	256	244	0	0	0.0
23	19.927	0	500	234	266	0	0	0.0
24	19.723	0	500	187	313	0	0	0.0
25	19.520	0	500	210	290	0	0	0.0
26	19.317	0	500	156	344	0	0	0.0
27	19.113	0	500	170	330	0	0	0.0
28	18.910	0	500	199	301	0	0	0.0
29	18.707	0	500	153	347	0	0	0.0
30	18.503	0	500	167	333	0	0	0.0

Experiment Number	Experiment Distance (mm)	No of components Fall off	No of components Pass By	Orientation B	Orientation A	No of Components in Orientation (B) Not Falling Off	No of Components in Orientation (A) Falling Off	Performance No %
31	18.300	0	500	150	350	0	0	0.0
32	18.097	0	500	160	340	0	0	0.0
33	17.893	0	500	165	335	0	0	0.0
34	17.690	0	500	170	330	0	0	0.0
35	17.487	0	500	95	405	0	0	0.0
36	17.283	0	500	132	368	0	0	0.0
37	17.080	0	500	167	333	0	0	0.0
38	16.877	0	500	105	395	0	0	0.0
39	16.673	0	500	110	390	0	0	0.0
40	16.470	0	500	111	389	0	0	0.0
41	16.267	0	500	120	380	0	0	0.0
42	16.063	23	477	82	418	59	0	4.6
43	15.860	26	474	150	350	124	0	5.2
44	15.657	38	462	158	342	120	0	7.6
45	15.453	94	406	164	336	70	0	18.8
46	15.250	120	380	157	343	37	0	24.0
47	15.047	175	325	190	310	15	0	35.0
48	14.843	150	350	165	335	15	0	30.0
49	14.640	185	315	195	305	10	0	37.0
50	14.437	178	322	185	315	7	0	35.6
51	14.233	187	313	207	293	20	0	37.4
52	14.030	177	323	182	318	5	0	35.4
53	13.827	177	323	177	323	0	0	64.6
54	13.623	210	290	210	290	0	0	58.0
55	13.420	191	309	191	309	0	0	61.8
56	13.217	215	285	215	285	0	0	57.0
57	13.013	190	310	190	310	0	0	62.0
58	12.810	220	280	220	280	0	0	56.0
59	12.607	221	279	221	279	0	0	55.8
60	12.403	204	296	204	296	0	0	59.2

Experiment Number	Experiment Distance (mm)	No of components Fall off	No of components Pass By	Orientation B	Orientation A	No of Components in Orientation (B) Not Falling Off	No of Components in Orientation (A) Falling Off	Performance No %
61	12.200	196	304	196	304	0	0	60.8
62	11.997	204	296	204	296	0	0	59.2
63	11.793	217	283	217	283	0	85	56.6
64	11.590	373	127	223	277	0	150	25.4
65	11.387	420	80	222	278	0	198	16.0
66	11.183	450	50	205	295	0	245	10.0
67	10.980	455	45	225	275	0	230	9.0
68	10.777	490	10	236	264	0	254	2.0
69	10.573	485	15	250	250	0	235	3.0
70	10.370	495	5	255	245	0	240	1.0
71	10.167	497	3	253	247	0	244	0.6
72	9.963	500	0	242	258	0	258	0.0
73	9.760	500	0	238	262	0	262	0.0
74	9.557	500	0	245	255	0	255	0.0
75	9.353	500	0	195	305	0	305	0.0
76	9.150	500	0	210	290	0	290	0.0
77	8.947	500	0	234	266	0	266	0.0
78	8.744	500	0	198	302	0	302	0.0
79	8.540	500	0	195	305	0	305	0.0
80	8.337	500	0	245	255	0	255	0.0
81	8.134	500	0	243	257	0	257	0.0
82	7.930	500	0	205	295	0	295	0.0
83	7.727	500	0	197	303	0	303	0.0
84	7.524	500	0	255	245	0	245	0.0
85	7.320	500	0	260	240	0	240	0.0
86	7.117	500	0	230	270	0	270	0.0
87	6.914	500	0	210	290	0	290	0.0
88	6.710	500	0	225	275	0	275	0.0
89	6.507	500	0	215	285	0	285	0.0
90	6.304	500	0	234	266	0	266	0.0

Experiment Number	Experiment Distance (mm)	No of components Fall off	No of components Pass By	Orientation A	Orientation B	No of Components in Orientation (A) Not Falling Off	No of Components in Orientation (B) Falling Off	Performance No %
91	6.100	500	0	245	255	0	255	0.0
92	5.897	500	0	234	266	0	266	0.0
93	5.694	500	0	256	244	0	244	0.0
94	5.490	500	0	267	233	0	233	0.0
95	5.287	500	0	220	280	0	280	0.0
96	5.084	500	0	198	302	0	302	0.0
97	4.880	500	0	195	305	0	305	0.0
98	4.677	500	0	210	290	0	290	0.0
99	4.474	500	0	245	255	0	255	0.0
100	4.270	500	0	215	285	0	285	0.0
101	4.067	500	0	233	267	0	267	0.0
102	3.864	500	0	187	313	0	313	0.0
103	3.660	500	0	235	265	0	265	0.0
104	3.457	500	0	267	233	0	233	0.0
105	3.254	500	0	190	310	0	310	0.0
106	3.050	500	0	245	255	0	255	0.0
107	2.847	500	0	260	240	0	240	0.0
108	2.644	500	0	237	263	0	263	0.0
109	2.440	500	0	276	224	0	224	0.0
110	2.237	500	0	254	246	0	246	0.0
111	2.034	500	0	234	266	0	266	0.0
112	1.830	500	0	265	235	0	235	0.0
113	1.627	500	0	234	266	0	266	0.0
114	1.424	500	0	198	302	0	302	0.0
115	1.220	500	0	185	315	0	315	0.0
116	1.017	500	0	232	268	0	268	0.0
117	0.814	500	0	243	257	0	257	0.0
118	0.610	500	0	265	235	0	235	0.0
119	0.407	500	0	233	267	0	267	0.0
120	0.204	500	0	276	224	0	224	0.0

Introduction

The vibratory bowl feeder is the most versatile of all hopper-feeding devices for small engineering parts. In this feeder (Fig. D.1), the track along which the parts travel are helical in form and pass around the inside wall of a shallow cylindrical hopper or bowl. The bowl is usually supported on sets of incline leaf springs secured to a heavy base and the support system constraints the movement of the bowl, so that it has tensional vibration about its vertical axis coupled with a linear vertical vibration. The motion is such that any part of the track vibrates along a short, approximately straight path, which is inclined to the horizontal at an angle greater than the track. When component parts are placed in the bowl, the effect of the vibration motion is to cause them to climb up the track to the outlet at the top of the bowl. (Boothroyd, 1981.)
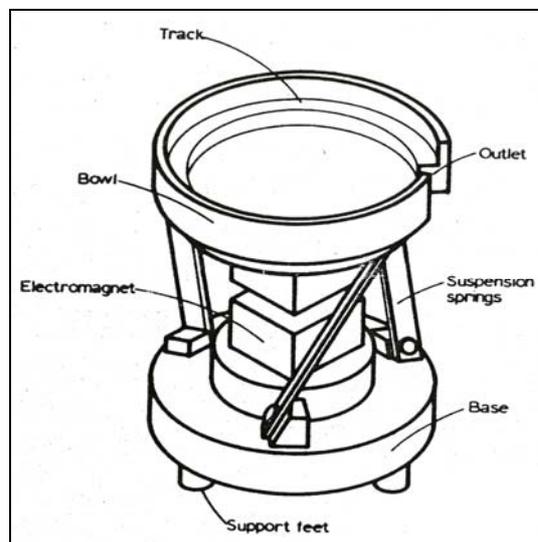
Fig. D.1: Vibratory Bowl Feeder (Boothroyd, 1981)

The process of presenting components that are correctly orientated is one of the primary operations performed by assembly machines. The development of Flexible Vibratory Bowl Feeding Tools may lead to a moor efficient VBF. This would contribute to a reduction in the cost and design of machines that use VBFs as bulk storage devices. Flexible VBFs would provide the safe transport of components at the required feed rate.

Each component will bring its own problems, but if the most suitable hopper feeder has been selected in the first place, it is likely that the subsequent engineering to achieve a reliable and sufficiently rapid supply of correctly orientated, undamaged components will be less difficult.

This chapter looks in detail at the mechanics of Vibratory Bowl Feeders from a theoretical point of view. It explains the terminology that is often used with vibratory part handling systems, and gives examples of where this technology was used in the Automated Vibratory Bowl Feeder project.

Mechanics of Vibratory Bowl Feeding

In the following analysis, the track of the vibratory feeder is assumed to move bodily with simple harmonic motion along a straight path inclined at an angle $(\theta+\varphi)$ to the horizontal as shown in Figure. D.2. The angle of inclination of the track is θ and φ is the angle between the track and its line of vibration. The amplitude of vibration a_o and the instantaneous velocity and acceleration of the track may all be resolved in directions parallel and normal to the track. These components will be referred to as parallel and normal motions and the normal motions will be indicated by the suffix n.
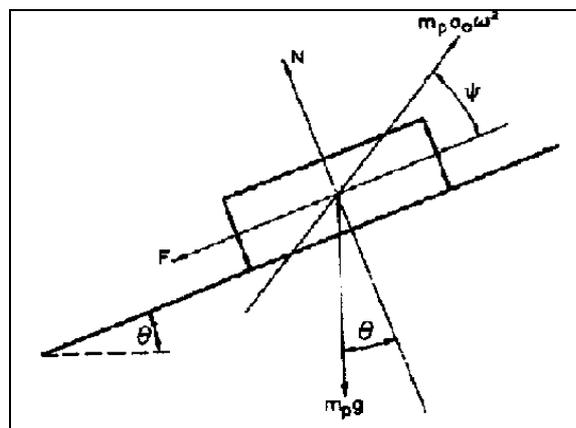
Fig. D.2: Force Acting on a Component in Vibratory Bowl Feeder
(Boothroyd, 1981)

It is assumed in the analysis that the motion of the part of mass m_p is independent of its shape and that air resistance is negligible. It is also assumed that there is no tendency for the part to roll down the track.

It is useful to consider the behaviour of the part that is placed on a track whose amplitude of vibration is increased gradually from zero. For small amplitudes the part will remain stationary on the track because the parallel inertia forces acting will be too small to overcome the frictional resistance F between the part and the track.

Figure D.2 shows the minimum inertia force acting on a part when the track is at the upper limit of its motion. This force has parallel and normal components of $m_o a_o \omega^2 \cos \varphi$ and mo $a_o \omega^2 \sin \varphi$, respectively, and it can be seen that for sliding up the track to occur.

$$m_o a_o \omega^2 \cos \varphi > m_p g \sin \theta + F \qquad (D.1)$$

Where

$$F = \mu_s N = \mu(M_p g \cos \theta - m_o a_o \omega^2 \sin\varphi) \qquad (D.2)$$

And where μ_s is the coefficient of static friction between the part and the track. The condition for forward sliding up the track to occur is, therefore given by combining equations (D.1) and (D.2). Thus

$$\frac{a_o \omega^2}{g} > \frac{\mu_s \cos \theta + \sin \theta}{\cos \varphi + \mu_s \sin \varphi} \qquad (D.3)$$

Similarly, it can be shown that for backward sliding to occur during the vibration cycle,

$$\frac{a_o \omega^2}{g} > \frac{\mu_s \cos \theta - \sin \theta}{\cos \varphi - \mu_s \sin \varphi} \qquad (D.4)$$

The operating conditions of a vibratory conveyor may be expressed in terms of the dimensionless normal track acceleration A_n/g_n, where A_n is the normal track acceleration $(A_n = a_n \omega^2 = a_o \omega^2 \sin \varphi)$, g_n the normal acceleration due to gravity $(= g \cos \theta$, and g the acceleration due to gravity $(= 9.81 m/s^2)$. Thus,

$$\frac{a_n}{g_n} = \frac{a_o \omega^2 \sin \varphi}{g \cos \theta} \qquad (D.5)$$

Substitution of Eq. (D.5) into Eqs. (D.3) and (D.4) gives:

For forward sliding:

$$\frac{a_n}{g_n} = \frac{\omega^2 + \tan \theta}{\cos \varphi + \mu_s} \qquad (D.6)$$

For backward sliding:

$$\frac{a_n}{g_n} = \frac{\omega^2 - \tan \theta}{\cos \varphi - \mu_s} \qquad (D.7)$$

For values of $\mu_s = 0.8$, $\theta = 3$ degrees (0.05 rad) and $\theta = 3$ degrees (0.52 rad), Eqs (D.6) and (D.7) show that the ratio A_n/G_n must be greater than 0.34 for forward sliding to occur and greater than 0.8 for backward sliding. With these conditions it is clear that, for all amplitudes of vibration giving a value of A_n/G_n greater than 0.34, forward sliding will predominate and the part will climb the track, sliding forward or both forward and backward during each vibration cycle.

The limiting condition for forward conveying to occur is given by comparing Eqs. (D.6) and (D.7). Thus, for forward conveying

$$\text{Tan } \varphi > \frac{\tan \theta}{\mu_s^2}$$

or, when θ is small,

$$\tan \varphi > \frac{\theta}{\mu_s^2} \qquad (D.8)$$

For values of $\mu_s = 0.8$ and $\theta = 3$ degrees (0.05), φ must be greater than D.7 degrees (0.08 radians) for forward conveying to occur.

For sufficiently large vibration amplitudes the part will leave the track and "hop" forward during each cycle. The condition for this to occur is where the normal reaction N between the part and the track becomes zero.

From Figure D.3,

$$N = M_p g \cos \theta - m_o a_o \omega^2 \sin\varphi \qquad (D.9)$$

And, therefore, for the part to leave the track

$$\frac{a_o \omega^2}{g} > \frac{\cos \theta}{\sin \varphi}$$

or

$$\frac{A^n}{g_n} > 1.0 \qquad\qquad (D.10)$$
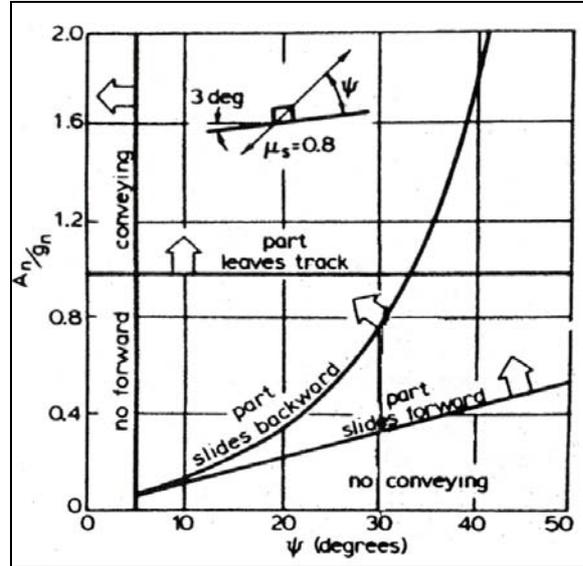
**Figure D.3 Limiting Condition For Various Modes of
Vibratory Conveying (Boothroyd, 1981)**

It is clear from the earlier examples, however, that the part would slide forward before it leaves the track during each cycle. Figure D.3 graphically illustrates these equations. This shows the effect of the vibration angle θ on the limiting values of the dimensionless normal acceleration A_n/g_n for sliding to occur, and for the part to hop along the track.

For all conditions, the part starts to slide forward at some instant when the track is nearing its upper limit of motion. When there is no hopping mode, this forward sliding continues until the track is nearing the lower limit of its motion, at which point the part may remain stationary, relative to the track, or slide backwards until the cycle is complete. In some cases, the stationary period is followed by a period of backward only or backward sliding followed by yet another stationary period. Finally, the forward sliding is followed by a period of backward sliding and then a stationary period to complete the cycle.

Analysis and experiment have shown that higher feed rates are obtained with the hopping mode of conveying (that is , $A_n/G_n > 1.0$). The modes of conveying are summarised in the following flow diagrams.
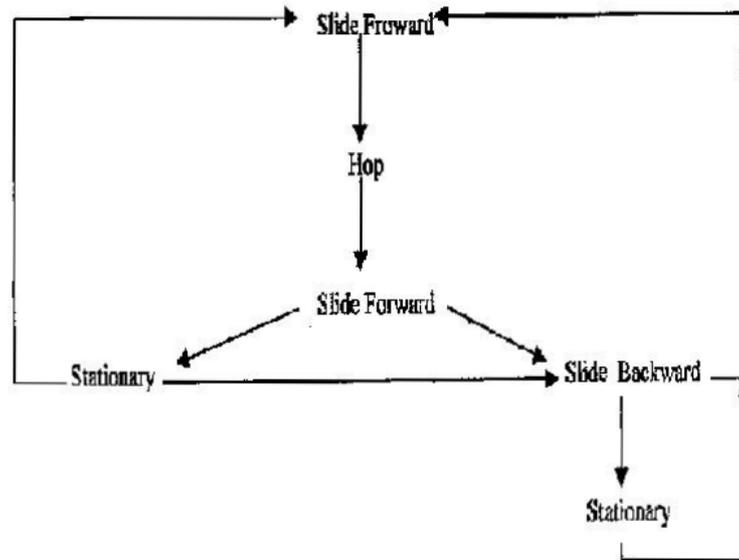
Figure D.4 Modes of conveying (Boothroyd, 1981)

Clearly a complete analysis of all the possible modes of vibration conveying is complicated. Such an analysis has been made and leads to equations that must be solved numerically with the aid of a computer. For the purpose of the present discussion it is considered adequate to describe only the main results of some experimental tests. In the following, the effects of frequency f, track acceleration A_n/g_n, track angle θ, vibration angle φ, and the effective coefficient of friction μ on the mean conveying velocity v_m are discussed separately.

Effect of frequency:

One principle result of the theoretical work is that for given conditions and for constant track acceleration (that is, An/gn is constant), the mean conveying velocity v_m is inversely proportional to the vibration frequency f.

Hence

$$f v_m = \text{constant} \qquad (D.11)$$

This is illustrated in figure D.5, where the effect of track acceleration on the mean conveying velocity is plotted for three values of the vibration angle φ. It can be seen that

the experimental point for a range of frequencies fall on one line when the factor fv_m is used as a measure of the conveying velocity.
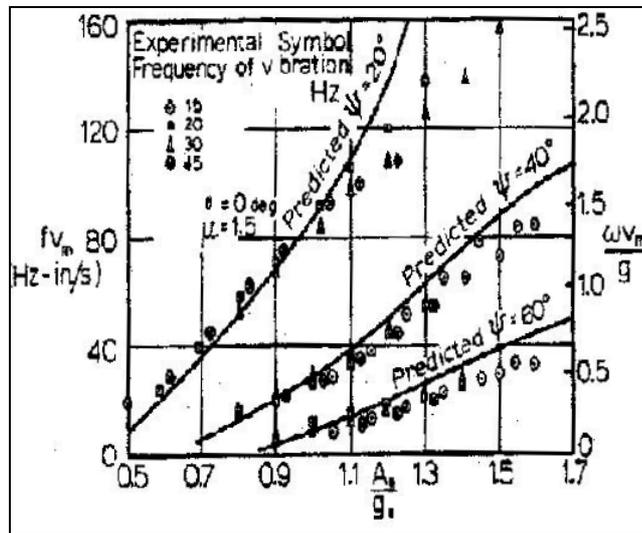
Figure D.5 Effect of Vibration Angle, Track Acceleration, and Frequency on Conveying Velocity (Boothroyd & Redford, 1967)

This varies the prediction of the theoretical analysis. One consequence of this result is that for high conveying velocities and hence high feed rates, it is desirable to use as low a frequency as possible. However, since the track acceleration must be kept constant, this result means a corresponding increase in track amplitude. The mechanical problem of connecting the feeder to a stationary machine imposes a lower limit on the frequency. The result of the experiment * in England have shown that some advantage is to be gained from lowering frequency of a bowl feeder from the usual 50Hz to 25Hz.

Effect of Track Acceleration

Figure D.5 shows than an increase in track acceleration A_n/A_g generally produces an increase in conveying velocity. At some point, however, although the theoretical analysis predicts further increases in velocity, increases in A_n/A_g cease to have significant effect. This finding may be explained as follows.

If the track acceleration is increased until $A_n/A_g > 1.0$, the part starts to hop once during each cycle as described earlier. At first, the velocity of impact as the part lands on the track is small but, as the track acceleration is increased further, the impact velocity also increases until, at some critical value, the part starts to bounce. Under these

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circumstances the feeding cycle becomes erratic and unstable and the theoretical predictions are no longer valid.

To obtain the most efficient feeding conditions, it is necessary to operate with values of A_n/A_g greater than unity but below the values that will produce unstable conditions. From Figure D.5 it can be seen that within this range, an approximately linear relationship exists between the factors fv_m and A_n/g_n for each value of φ and for given values of track angle, θ, and the coefficient of friction, μ.

Effect of Vibration Angle

From Figure D.5 it can be seen that the conveying velocity is sensitive to changes in vibration angle φ. The effect is shown more clearly in Figure D.6, which indicates that an optimum vibration angle exists for given conditions. For clarity, these theoretical predictions are for given conditions. Previously work has resulted in the relationship between optimum vibration angle φ_{opt} and the coefficient of friction (Fig, D.7) for a practical value of track acceleration where A_n/g_n is 1.2.
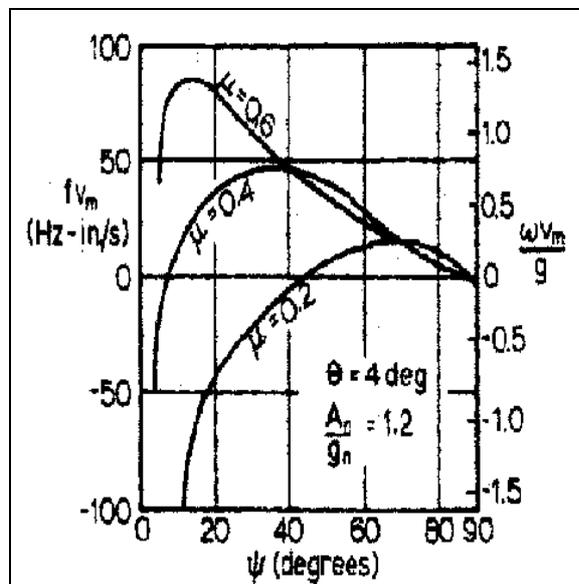
Fig, D.6: Theoretical Results Showing the Effect of Vibration Angle on the Mean Conveying Velocity (Boothroyd & Redford, 1967)
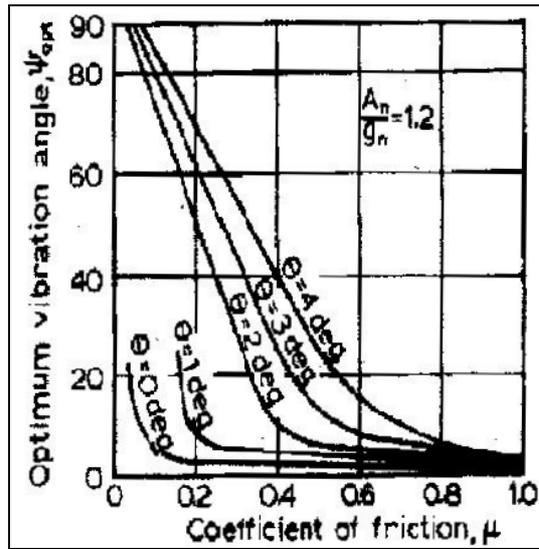
Fig. D.7: Theoretical Results Showing the Effect of Coefficient of Friction on the Optimum Vibration Angle (Boothroyd & Redford, 1967)

Effect of Track Angle

Figure D.8 shows the effect of track angle θ on the conveying velocity for various track accelerations when μ is 0.2. These results show that the highest velocities are always achieved when the track angle is zero and second, that forward conveying is obtained only with small track angles. The mechanical design of a bowl feeder necessitates a positive track angle of three to four degrees in order to raise the part to the bowl outlet. However, it can be seen from the figure that even if conveying can be achieved on the track, the mean conveying velocity will be significantly lower than that around the flat bottom of the bowl. This means that in practice, that parts on the track will be invariable be pushed along by those in the bottom of the bowl, which will tend to circulate at a greater speed. This leads to certain problems in the design of orienting devices, which are generally placed around the upper part of the bowl track. During the test of such orienting devices, parts transported individually along the track may behave correctly. However, when the bowl is filled with parts and a line forms along the track, the parts tend to be forced through the orienting devices by the pressure of those in the bottom of the bowl. This may often lead to jamming and general unreliability in operation.
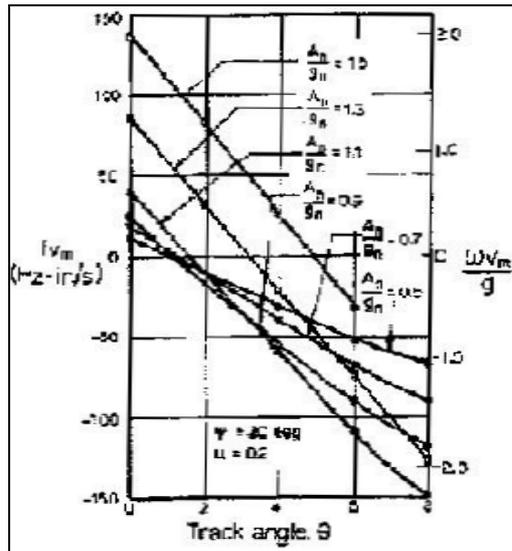
Fig. D.8: Theoretical Results Showing the Effect of Track Angle on the Conveying Velocity (Boothroyd & Redford, 1967).

From the forgoing discussion it is clear that when considering the unrestricted feed rate from a bowl feeder, a track angle of zero degrees should be employed because the feeding characteristics in the flat bowl bottom will generally govern the overall performance of the feeder.

Effect of Coefficient of friction

The practical range of the coefficient of friction in the vibratory feeding is from 0.2 to 1.0. The figure of 0.2 is representative of a steel part conveyed on a steel track. By lining the track with rubber, a common practice in industry, the coefficient of friction may be raised to approximately 0.8.

Figure D.9 shows the effect of coefficient of friction on the conveying velocity for a horizontal track, a vibration angle of 20 degrees, and for various track acceleration, an increase in friction leads to an increase in conveying velocity, hence the advantage of increasing friction by coating the tracks of the bowl feeders with rubber. Coatings can also reduce the noise level due to motion of the parts, a consideration that is often of paramount importance.
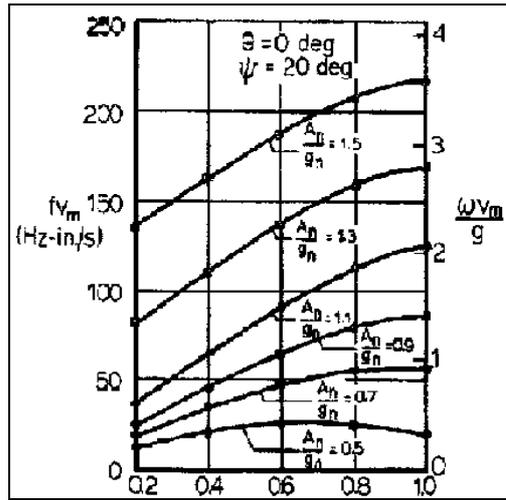
Figure D.9: Theoretical Results Showing the Effect of Coefficient of Friction on the Conveying Velocity(Boothroyd & Redford, 1967)

Estimating the Mean Conveying Velocity

At any point on the horizontal track, the ratio of the amplitudes of the vertical and horizontal components of vibration is equal to the tangent of the vibration angle φ. When the bowl is operating properly with no rocking motion, the vertical component of motion a_n will be the same at every location in the bowl. The magnitude of the horizontal component a_p. However, changes with radical position.

The horizontal component increases linearly with increasing radial position. If the vibration angle φ at radial position r_1 is known, the vibration angle φ at the radial position r_2 is found from.

$$\text{Tan } \varphi 2 = \frac{r_1}{r_2} \tan \varphi_1 \qquad (D.12)$$

If the leaf springs are inclined at 60 degrees (1.05 rad) from the horizontal plane and attached to the bowl 100mm from the bowl centre, the vibration angle at this radius is the compliment of the spring inclination angle 30 degrees (0.52 rad) if the vibration of the base is neglected. If the vibration of the base is important, the vibration angle should be determined experimentally by comparing the signals from two accelerometers: one mounted vertically, the other mounted horizontally. The value of the vibration angle at a radial position 150mm from the bowl centre can be found from Eq. (D.12) and is

$$\varphi = \arctan \left(\frac{100}{150} \tan 300\right) = 210 \ (0.37 \text{ rad}) \qquad (D.13)$$

The vibration motion of the bowl feeder causes part, randomly deposition in the bottom, to climb the helical track on the interior of the bowl wall. The conveying velocity of the parts on the inclined track is usually governed by the pushing action of the parts circulating around the bottom of the bowl, the conveying velocity v_n depends mainly on the vibration angle φ, the amplitude of vibration a_o, and the frequency of vibration ω, where ω equals $2\pi f$. A simple dimensional analysis of this situation shows that

$$\frac{vm\omega}{g} = \text{function } \left(\frac{a_o \ \omega^2 \sin \varphi}{g}\right), (\varphi) \qquad (D.14)$$

where g is the acceleration due to gravity and is equal to 9.81 m/s^2. The functional relationship from Eq. (D.14) is presented graphically in Figure D.10 for the usual case of 50Hz vibration, the conveying velocity is also shown as a function of the vibration angle φ and the vertical amplitude of vibration, that is, the amplitude normal to the horizontal track. The dimensionless scales show in Figure D.10 can be used for any vibration frequency including 50Hz, but this requires additional computation.
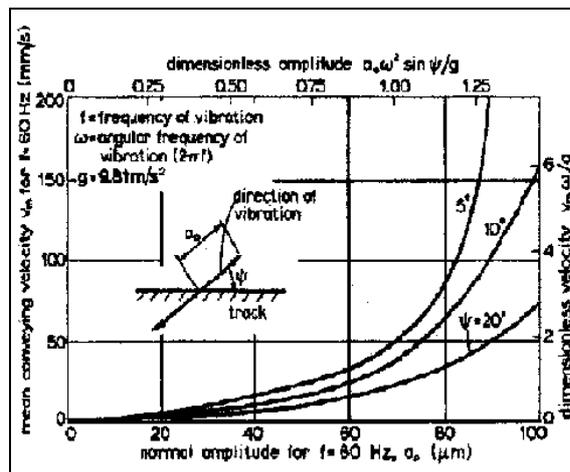
Fig. D.10: Estimating the mean conveying velocity on a Horizontal Track (Boothroyd, 1981).

For example suppose that a 60Hz vibratory bowl feeder has a start of the track, on the bottom of the bowl, located 150mm from the bowl centre, and the vibration angle at this point is 21 degrees (0.37 rad). Then according to Figure D.10, the conveying velocity v_m

is approximately 35mm/s when a_n is 80 µm. As a comparison, if an or a_o sin φ equals 80 µm, the value of the dimensionless amplitude

$$\frac{A_0\, \omega^2\, \sin \varphi}{g} = \frac{(80 \times 10^{-6})(2\pi 60)^2}{g} = 1.16 \qquad\qquad (D.15)$$

From Figure D.10, if h equals 21 degrees ().37 red0, the dimensionless velocity $v_m\, \omega/g$ equals 1.35 and v_m equals 35mm/s. The corresponding value of the horizontal amplitude a_p is 210 µm.

The vibration amplitude is usually set while observing a special decal mounted on the outer rim of the bowl. This decal is used to measure the peak to peak amplitude or twice the horizontal amplitude of vibration at this point. The correct value of this horizontal amplitude depends on the bowl diameter and is found from geometry.

Using the previous example on a bowl 600mm in diameter, the parallel amplitude at the rim is so that the peak-to-peak setting is 0.84mm.

$$\frac{300}{150} (210) = 420 \ \ \mu m \qquad\qquad (D.16)$$

As a consequence, the vibration angle for the last horizontal section of the track is

$$\arctan \left(\frac{80}{420}\right) = 11^0 \ (0.19 \text{ rad}) \qquad\qquad (D.17)$$

As the parts leave the bowl there conveying velocity is 70mm/s, from Figure D.10.

Although parts are apparently conveyed by vibration motion with an almost constant conveying velocity, this motion is, in actuality, a combination of a variety of dissimilar smaller motions is cyclic and usually repeats with the frequency of the drive. Some of the details of this motion are important in the design of orienting devices used in the vibratory bowl feeders. Figures D.11 and D.12 show the effective length J and the height H of a hop for a point mass travelling on a horizontal track as shown in Figure D.13. the

effective length of the hop is the smallest gap in the track that will reject all point masses travelling with this motion.

The magnitude of this effective hop can be determined from Figure D.11. If the normal amplitude an is 80 μm for 50 Hz vibration and the vibration angle φ is 11 degrees (0.19 rad), then from this figure the value of the effective hop is 0.6mm. Scales on the top and right side of Figure D.11 can be used fro other frequencies of vibration, as explained in the discussion of Figure D.10.
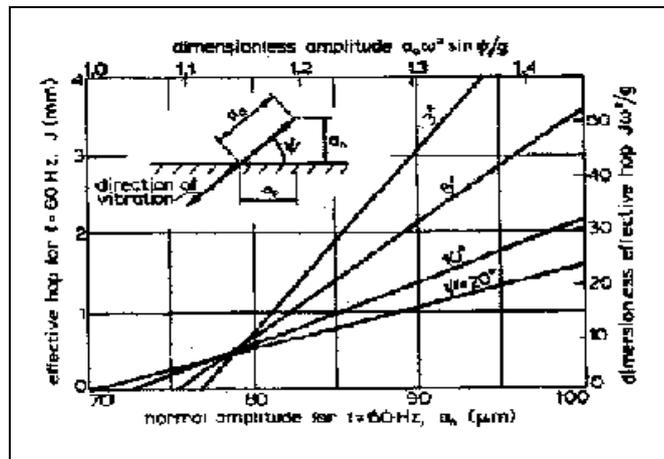
Fig. D.11: Theoretical Estimate of the Length of the Effective Hop on a Horizontal Track (Boothroyd, 1981)

Similarly, Figure D.12 can be used to determine the magnitude of the maximum height H of the hop above the horizontal track. Using the previous conditions (an = 80 μm and 50 Hz), H is 8 μm.
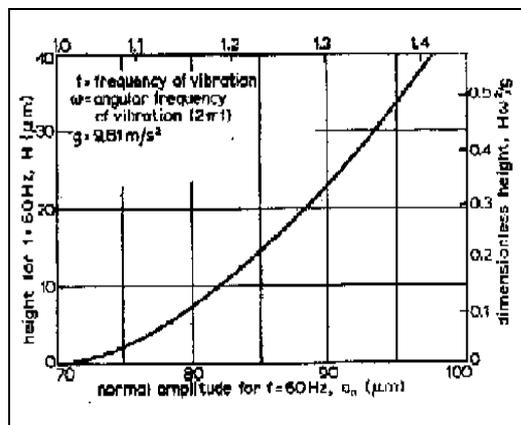
Fig. D.12: Theoretical Estimate of the Maximum Height Reached by a Hopping Part above a Horizontal Track (Boothroyd, 1981)

Load Sensitivity

One of the main disadvantages of vibratory bowl feeders is there change in performance as the bowl gradually empties. This change occurs because, for a constant power input, the amplitude of vibration, and hence the maximum bowl acceleration, usually increases as the effective mass of the loaded bowl reduces. It can be deducted from Figure D.14 that this increase in bowl acceleration will generally result in an increase in the unrestricted feed rate (Boothroyd, 1981).
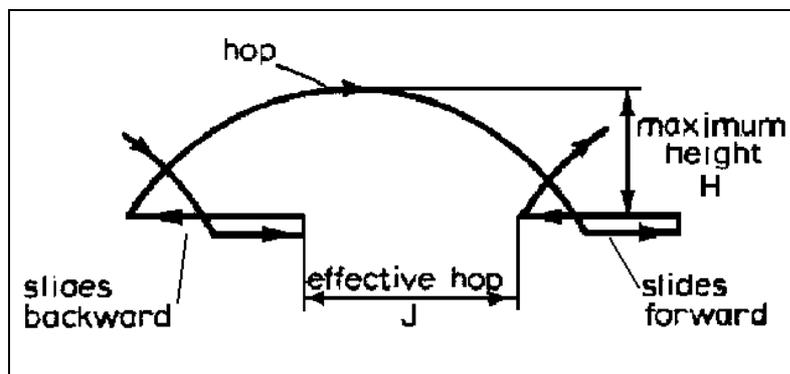
Figure D.13 Typical Part Motion, Including the Hop (Boothroyd, 1981)
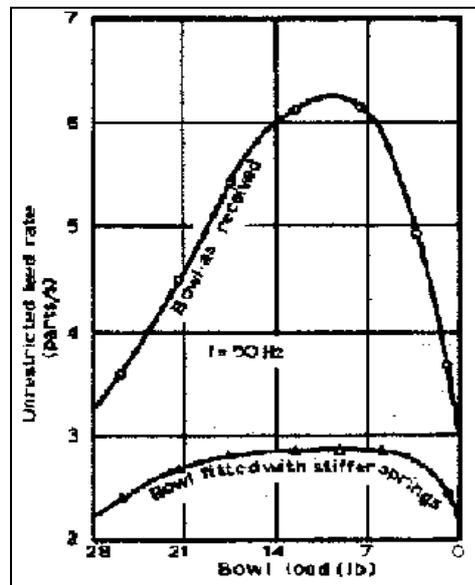
Fig. D.14: Experimentally Determined Load Sensitivity of a Commercial Bowl Feeder (Boothroyd & Redford 1967)
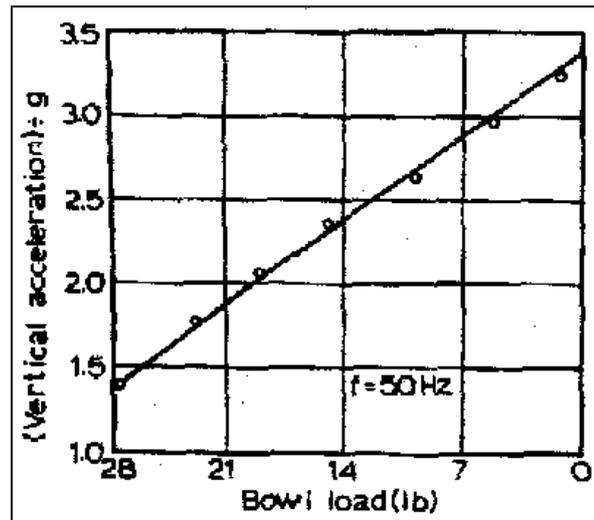
Figure D.15 Effect of Bowl Load on Bowl Acceleration
(Boothroyd & Redford, 1967)

Vibratory bowl feeders are often used to convey and orient parts for automatic assembly and, since the workheads on an assembly machine are designed to work at a fixed cycle time, the parts can only leave the feeder at a uniform rate. The feeder must therefore be adjusted to overfeed slightly under all conditions of loading, and excess parts are continuously returned from the track to the bottom of the bowl.

The change in performance as a feeder gradually empties is refered to as its load sensitivity and the upper curve in Figure D.14 shows how the unrestricted rate for a commercial bowl feeder in the as received condition varied as the bowl emptied. It can be seen that the maximum feed rate occurred when the bowl was approximately 100% on the feed rate obtained with the bowl full. It is interest to compare this result with the measured changes in bowl acceleration shown in Figure D.15, where it can be seen that the bowl acceleration, and hence the amplitude, increased continuously until the bowl became empty. Clearly when a feeder empties, the feed rate will reduce to zero, but Figure D.14. shows that the feed rate begins to reduce much sooner than might be expected from Figure D.15. This behaviour is considered to be due to the greater velocity of the parts in the flat bowl bottom than that on the track; this was described earlier. When the bowl is full, the feed rate depends mainly on the feeding characteristics in the bottom of the bowl, where the general circulation of the parts pushes those on the track. However, when the bowl empties sufficiently so that its contents are mainly held on the track, the pushing action ceases and the feed rate depends on the conveying velocity on

the incline track, which is generally lower than that on that horizontal surface. This explains the difference in character between the graphs in Figure D.14 and D.15.

Figure D.14 suggests that under test conditions the as-received bowl feeder could be used to feed a workhead operating at a maximum rate of 3 cycles per second and that in this case there would be considerable recirculation of the parts due to overfeeding. Assuming that the feeder is to be refilled when it becomes 25% full, the feeding characteristics between refills may be reasonable represented by a feed rate increasing linearly as the bowl empties. An analysis is now presented that may be used to estimate the unnecessary recirculation of the parts in a bowl feeder with this characteristics.

Terminology used with vibratory part handling systems

The next section gives a brief explanation of terms and devices that are commonly used by vibratory bowl manufacturers and users of bowls.

Basic Bowl

An untooled bowl consists of a vertical band and a domed bottom with either an external helical track or an internal helical track. The internal track can also be inverted.

Angular Skirt

A conic section calculated to fit at the required angle attached between the bottom side of the track and the bowl wall to prevent parts from stacking, and causing jams between the tracks.

Tooled Bowl

The basic bowl complete with internal and external tooling designed to meet feed rate, part orientation and other specifications as required. Angular Skirt.

Parallel Blade Section

An area with a stationary or adjustable gap that orients parts (bolts, screws, etc.) to a "hanging attitude". (See Figure E.1)
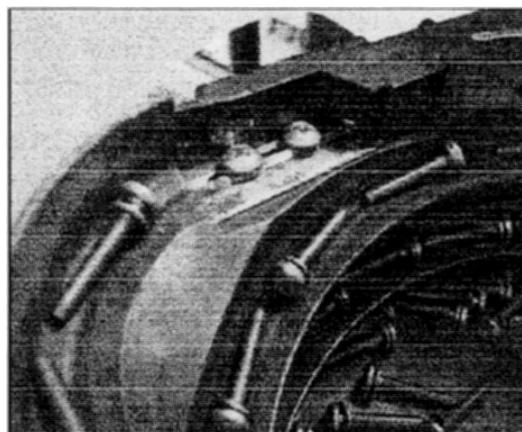
Fig. E.1: Parallel Blade Selection. AMTLAB

Orientation

The correct position of the part at the discharge chute as required by the assembly or placing operation.

External Tooling

Any construction outside of the vertical band, which separates, orients, selects, confines, or relieves pressure build-up on orientated parts. (See Figure E.2)
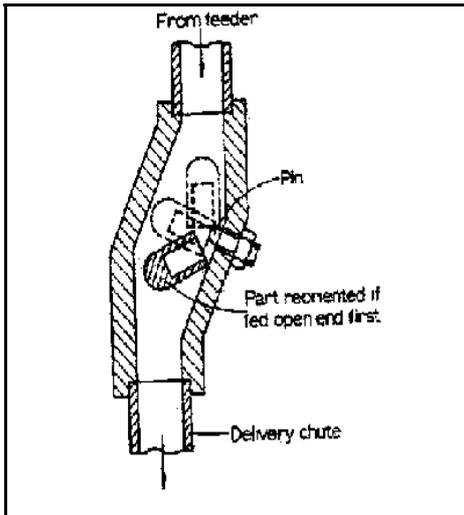
Fig. E.2: External Tooling (Boothroyd, 1981)

Rate

The number of parts discharged per minute or hour, as needed to maintain production requirements.

Cord Section

A straight section of either stainless or tool steel used to select or orient parts.

Baffle

A stainless steel deflector welded to the bowl bottom to guard the return hole, thus allowing parts to flow evenly back from the return pan.

Air Jet

A small diameter tube mounted in place, which is sometimes used to assist part movement. It is adjusted in the process of development to assist in orientation or final selection with the minimum amount of air pressure. (See Figure E.3)
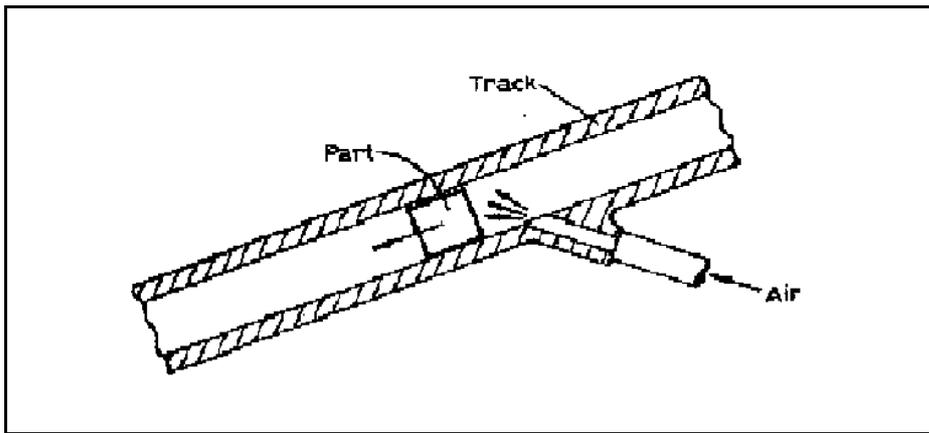
Fig. E.3: Airjet (Boothroyd, 1981)

Pre-Orientor

Tooling to change the attitude of a part to the proper position for final selection. A pre-orientor will generate higher feed rates' and minimise re-circulation of the parts, thus extending the life of the bowl, especially with regard to metal or abrasive parts.

Back Pressure Relief (or "Bubble")

An area of the bowl tooling prior to the entrance of confinement, where the parts will buckle if the discharge is full and re-circulate in the bowl. This relieves part pressure, which would otherwise cause jamming conditions or miss-oriented parts to bridge across the bowl tooling.   (See Figure E.4)
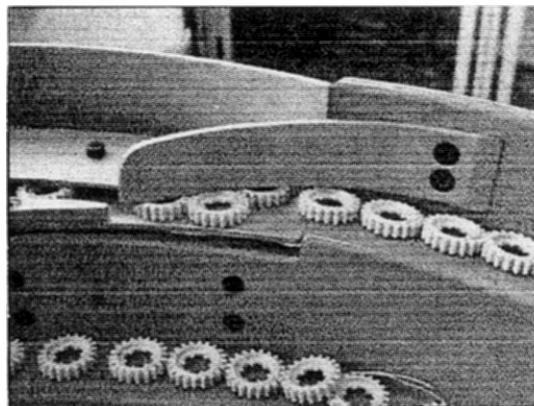
Figure E.4 Back Pressure Relief AMT Lab

Full Track Sensor

A means of providing a pressure relief when the parts will not efficiently bubble-off

of their own accord. This device can be a proximity, fibre optic, or pneumatic type sensor to signal the feeder to start or stop. Also, a sensor can activate an air jet to eject excess parts from the entrance to confinement, in which case the 'bowl would continue to run. (The latter is most generally used with multiple track bowls). (See figure E.5)
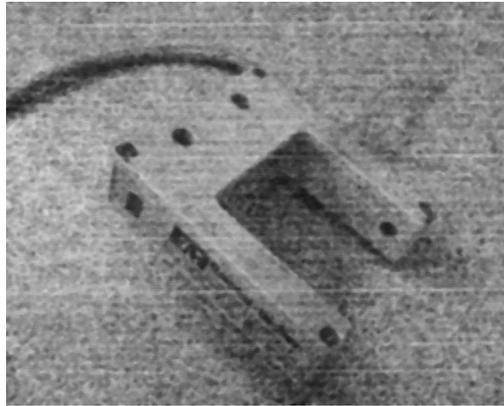
Fig. E.5: Full Track Sensor (AMTLAB)

Scrap Chute

A scrap chute is used to discharge small particles of foreign material from the bowl without interfering with flow of the piece parts.

Confinement

A containing section used to control parts through the discharge chute. Confinements are designed in a manner to allow access to the parts by removal of "bolt-on" sections in most cases.

Sweep (or Cam)

A stainless or tool steel insert placed above a track to control the part level or orientation.

Flange Mount

This is a continuation of the band below the bowl bottom to hold it to the cross arms of the base drive unit. Clamp nuts are used to attach small diameter bowls to the top member. On large diameter bowls, clamp nuts, along with a centre bolt are provided.

Discharge Chute (Horizontal or Down Angle)

A short section of track that is mounted to the bowl. The discharge chute controls parts in the orientation, achieved in the bowl and in most cases, conveys then to either a horizontal vibratory straight line or gravity track. (See figure E.6)

Fig. E.6: Discharge Chute (AMTLAB)

Quick Dump Chute

A quick-opening "window" that is provided to facilitate changing from one part to another when multiple sizes or sizes of parts are been fed from the same bowl.

Running Surface

That portion of the basic bowl, pre-orientor, final selector or discharge chute with which the parts make contact. This is a variable dimension, depending upon the particular piece part.

Counter-Balance Weight

A solid steel block of pre-determined size and weight that is added to the exterior of the bowl. The location is determined on a counter-balance wheel, in order to offset the weight of the external tooling, etc. (static balance).

Storage Hopper

A storage hopper is used to hold extra parts for replenishing the supply in the bowl. Hoppers are set to operate automatically by a signal from a level control switch, thus eliminating either a deficiency or an over-supply of parts in the bowl. (See Figure E.7)
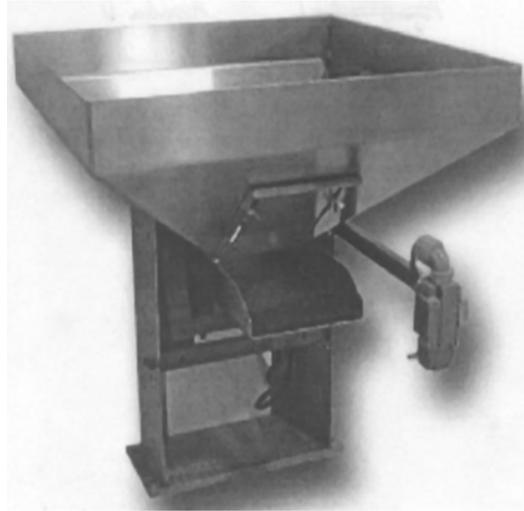
Figure E.7 Storage hopper (AMTLAB)

Gravity Tracks

Gravity tracks and vertical magazines are methods of conveying parts. This type track must be set on an angle great enough that gravity will convey the parts from the discharge chute of the feed system. A magazine is a track in which oriented parts are stacked.

Final Selector

A tooled selection designed specifically to segregate only those parts that are in the correct control orientation. (See Figure E.8 overleaf)
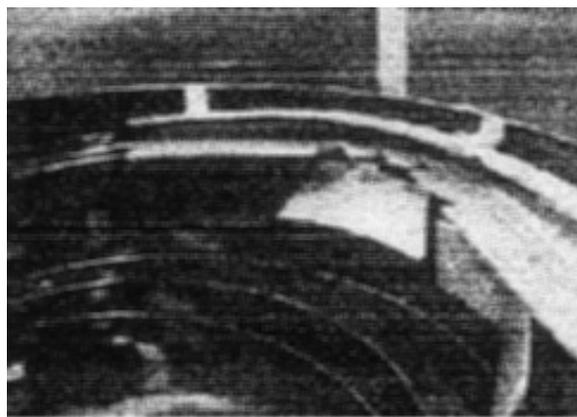
Figure E.8 Final Selector Nortan Waterford Ltd

Adjustable Narrow Track Section:

A short section of track that can be set at various widths. The length depends on the size of the part. This may be either a stainless or tool steel insert that can be adjusted

to either orient or limit parts to a single file.

Escapement

A mechanical device placed at the end of the feeder discharge, horizontal straight line, or gravity track to isolate the end part. (The escapement in figure E.9 uses a pneumatic cylinder to lift the component up as it is fed in. Figure E.10 shows a drawing of two type of escapement)
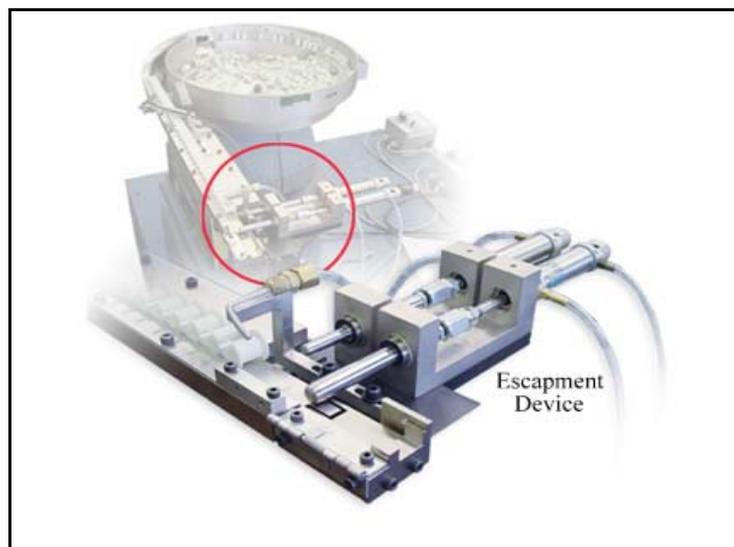
Figure E.9 Escapement Device (AMTLAB)
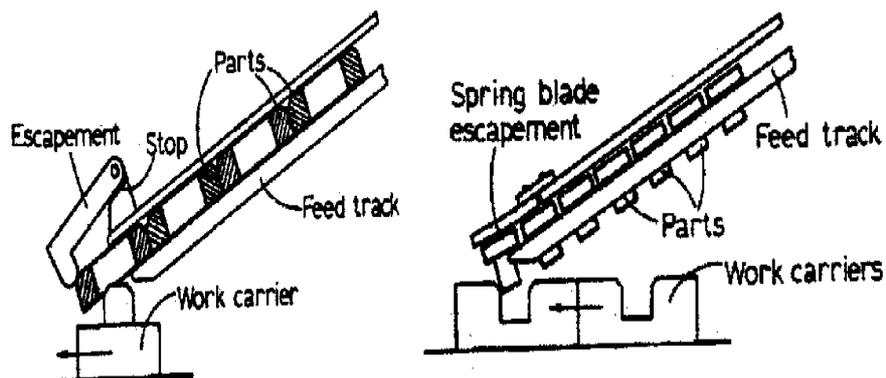
Fig. E.10: Escapement Devices (Bothroyd, 1981)

Placing Device (Head)

A mechanical means of placing an escaped part into a nest or onto another piece part.

Base Drive Units:

The force unit used to power the Drive Unit is accomplished by using one or more electromagnetic coils, which act upon pole faceplates to generate vibratory motion. The upper and lower members of the drive unit are constrained by leaf springs causing torsional vibration that is transferred to the top member in the form of feed motion. When the drive unit moves the parts at the maximum efficiency with minimum current effect, the unit is correctly tuned to a natural frequency of the power source. The mass and the diameter of the feeder bowl is the determining factor in tuning the unit. As this mass or diameter is increased, more leaf springs must be added. The rubber feet of the base drive play an important part in allowing the lower member of the drive unit to act as a pendulum to power the bowl.

Coil Clatter:

A warning sound, which indicates that the coil gap is set too close, causing the pole faces to strike. This condition will result in damage to the drive unit if not corrected.

Clamp Nuts:

A machined block at the end of each cross arm of the upper weldment for the purpose of attaching the bowl to the unit. Failure to do so will result in failure or malfunction of the feeder system.

Motion and Transfer:

A vibratory bowl literally causes piece parts to travel up-hill, as they vibrate up inclined ledges, or tracks, spiralling around the inside of the bowl. The physics creating this phenomenon is the vibration in the acceleration motion during the vibration cycle causing the parts to be tossed upward. The direction of the vibration motion is canted to provide two components, one parallel to travel in the track and one perpendicular to the track (i.e., vertical). The frequency of the vibration can be varied with increasing frequency resulting in faster feed rates up to a limit beyond which increasing frequency results in slower feed rates. One of the principle features of vibratory bowls is recycling, the restart of components that either fall off the tracks or have been rejected by the parts orientation mechanism along or at the top of the track.

Orientation and Selection:

Along the top of the bowl will be found some subtle irregularities in the inclined track that have been designed to recognise the geometry of the particular part being fed. These irregularities are designed to push, dump, or otherwise incorrectly orientated parts to fall back down into the bowl for a retry at correct orientation. The headed screw or rivet is a good example. Figure E.11 below shows several clever tricks to obtain the desired orientation of the rivets into the slot on the left, rivet head up. Taking advantage of the fact that the rivet is longer than the diameter of its head, a wiper blade diverts all rivets standing on their heads.

Next, a pressure brake causes the line of rivets to buckle if the delivery slot is too full to accept new rivets at the rate they are being pushed up from below. The pressure brake also is a track-narrowing device that ensures that the line of the rivets will arrive single file at the delivery slot. However, even at its narrowest point, the track accommodates the rivet turned either shank or head forward.

Now note the slot, which is wide enough for the shank but not the head. The shank will fall into the slot whether the head or the shank is trailing. If the rivet is turned somewhat diagonally on the track so that the shank misses the slot, the downward slope on the inside shoulder of the slot causes the rivet to fall back into the bowl for a retry (Asfahl, 1992).
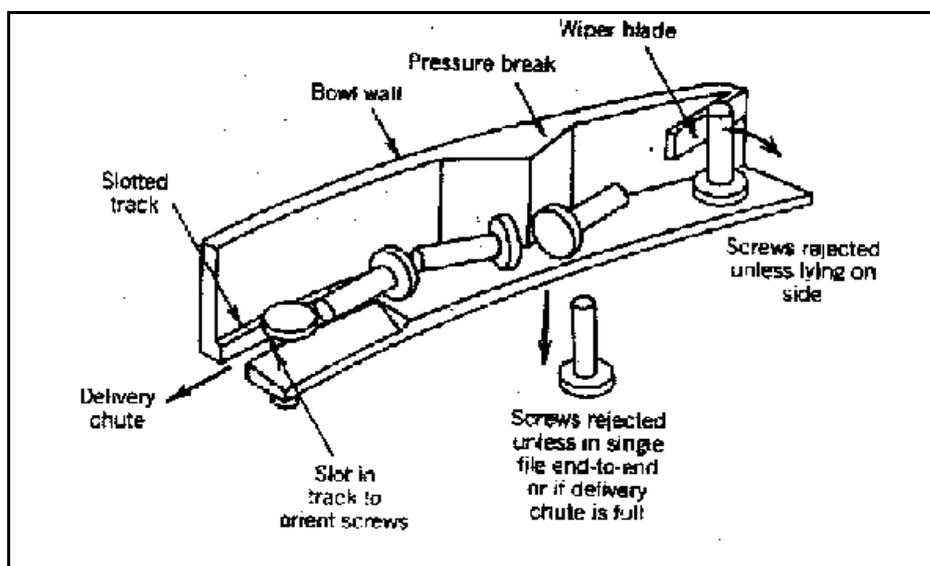
Fig. E.11: Orientating Headed Screws or Rivets at the Top Discharge Position of a Vibratory Bowl (Boothroyd, 1981)

Curiously, in some cases part symmetry can be beneficial to automation, and in some cases symmetry can make automation nearly impossible. Consider the example shown in Figure E.12 and Figure E.13 below. In some of these examples, both ends were designed to be identical to make orientation unnecessary. In two of the examples, the achievement of symmetry requires additional details to be fabricated into the part, but the additional fabrication cost would be minimal compared to the costs of achieving parts orientation for the corresponding asymmetrical designs. Figure E.14 however presents a different problem. In these examples, important features on each part are difficult to detect mechanically, and the solution to the problem is to remove symmetry. On one part, a projection is added on one side on a basically disk-shaped part. On another, a flat is milled on a cylindrical surface to indicate the angular position of a hidden hole through the shaft. On the third, a pin is used for a similar purpose to locate around a disk the angular position of a hole whose axis is parallel to the centre line of the disk.
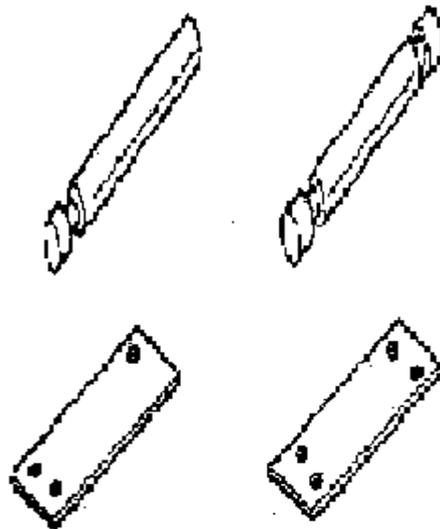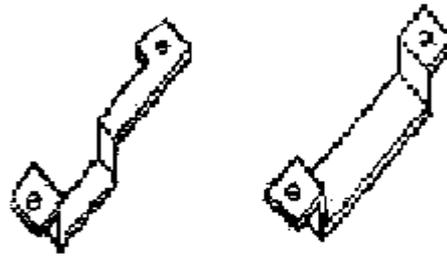
Fig E.14: Design for Automation Feeding and Orientation (Boothroyd, 1981)
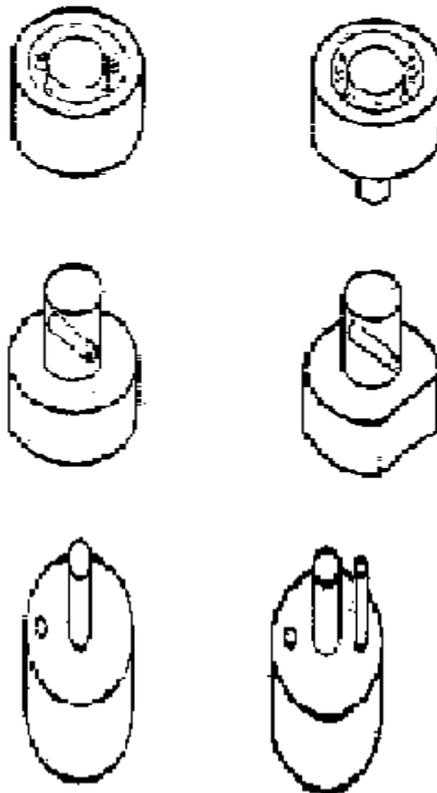
Fig. E.15: Design for Recognition of Features (Boothroyd, 1981)

In each case, the part lost some of its symmetry in the re-design to make automation more feasible. Disk and circular objects are particularly good candidates for asymmetric design features, because without locating features they can assume an infinite number of rotational orientations. Rectangular shapes, however, usually benefit from symmetry because there are only a few feasible orientations, and frequently the designer can make all of these orientations workable.

Installation and Trouble-Shooting Guide for Vibratory Bowls and Drive Units: (Extracted from www.mcknight.on.ca WebPages)

When the vibratory drive unit will not transmit power to the vibratory bowl, it is often caused by one of the following reasons:

- The power supply to the control may be inadequate;
- The cord from the feeder to the control may be improperly connected or damaged;
- A fuse may be blown in the drive unit controller;
- A coil may be shorted out in the drive unit;
- The gap between the the coil and armature may be too closed or too wide;
- A piece part of a foreign object may be lodged between the coil and armature;
- The feeder bowl may be in contact with a rigid track, or the bowl or base drive   unit may be making contact with other equipment.

When a vibratory feeder has an insufficient amount of vibration or slow sporadic or irregular parts movement, it is usually due to one of the following reasons:

- One or more springs in the drive unit may be loose, cracked or broken;
- It may be mounted on a base plate that is too thin which can cause an "oil can" effect, or flexing, that will absorb useful vibration;
- The base plate may be mounted improperly, lacking rigidity. The feeder may be mounted on a common base plate that overhangs the machine base, thus generating insufficient vibration for parts movement. (The top plates on column-type stands or tables should be a minimum of 32mm thick, so that they will not absorb vibration. Column-type stands should have gussets to add strength);
- The table may not be level or lagged down properly;
- There may be a accumulation of foreign material on the bowl tracking surfaces;
- The coil gap may be improperly set. The gap should be set as close as possible, without the pole faces striking (pole faces should be parallel);
- The machine may be cycling or indexing so sharply that it causes parts to fall from the tooling of the vibratory bowl;
- The voltage to the controller may be fluctuating;
- The base drive unit may need re-tuning to the power supply that is available in the area;

- The parts may be out of tolerance, have burns on them, be bent, warped or have oil, mould release, or some type of lubricant on them, which prevents proper movement.

- The bowl clamp nuts, which fasten the bowl to the crossarms, may not be tight or the bowl may not be properly seated in the clamp nuts. This is VERY important;

- The bowl may be overloaded with parts. If overloaded, the vibratory motion will be erratic. There is a load range in vibratory feeding equipment that, if exceeded, will cause a loss of efficiency. Due to differences in part size, weight and configuration, the load for a feeder must be established by adding layers of parts to the bottom of the bowl until the proper level is found for the most efficient operation. (Part level can be automatically maintained by a properly installed and adjusted auxiliary supply hopper);

- The bowl may not be tuned properly. Vibratory feeder tuning consists of the addition or removal of springs in the base drive unit. This balances the spring tension in proportion to the weight of the bowl that is mounted on it.
  Occasionally, after receiving a feeder, the piece part will be altered. Changes of part configuration will require new tooling on the bowl and re-tuning of the drive unit.

- The use of air jets present problems when they are not set properly (pressure set too high or too low). Some things to look for:

- Is the air supply contaminated?

- Does the airline contain water or oil?

- If so, this contamination will accumulate on the running surfaces of the bowl and create a condition that will slow down part movement or actually stop it.

- All air to a feeder system must be dry, filtered and regulated to achieve peak efficiency.

- A regulator must be used to provide a consistent flow, eliminating the high and low-pressure factor. And each air jet should be metered with a separate flow control valve.

- Attaching rigid lines or hard plastic tubing must be avoided as it dampens vibration and will cause problems with feed rates, as well as other tuning problems.

- Flexible nylon tubing or other soft material tubing should be used to prevent interference with vibration from a base drive unit.

- The power supply from the controller may not be the proper frequency.

Procedures for Tuning the Base Drive Unit:

(Extracted from www.mcknight.on.ca WebPages)

The following procedures should be used to check the tuning of any 50 or 100 Hz base drive unit:

IMPORTANT! Before tuning the unit, make sure there are no cracked or broken springs that all the bolts are torqued, and the magnet poll faces are set at the proper gap.

With the variable speed controller on the proper level of the parts in the bowl, set the dial at 35% to 40% of the input voltage. Some parts movement should be detected at this point. If the feed rate is too slow, increase the controller setting slowly until the desired feed rate is attained. When 80% of the input voltage has been used without reaching the desired amplitude or there is excessive or sporadic vibration, check for interference points where something may be contacting the bowl or base drive unit, then follow these turning techniques to achieve maximum efficiency:

Loosen a bolt on any one of the spring clamp blocks (preferably a lower bolt), very gradually, until the unit either speeds up or slows down. If the unit speeds up, it is over sprung. If the unit is over sprung, the thinnest spring from two opposing hangers must be removed. When replacing the springs they must be torqued as specific in "Base Unit Torque Requirements".

If after this change, there is an under sprung reading (if unit slows down when a bolt is loosened), thinner springs must be added back to the two opposite hangers. IMPORTANT! To maintain consistent, even fed motion, the number of springs in opposing spring packs must be equal.

The base unit should be slightly over tuned, but the degree of over turning must be established.

Springs tend to work-harden on a base drive unit that has been in operation for a period of time, causing it to be over tuned.

If a unit indicates that it is still under sprung after a spring has been added, check for a spring that may be cracked or broken. This usually happens on the bottom portion of the spring, near the spring clamp hanger.

In some cases, the crack cannot be seen because of paint or because it may not be all the way through to the point where it is easily visible. It should be removed and inspected closely for hairline cracks.

Make sure the bolts are long enough to fasten the springs to the spring hangers. For example, if a 10mm thick spring has been added, there will be 10mm less of the threads to hold the springs. When tightened, the threads may strip and the unit will give a false tuning reading. The same also applies to the bolts holding the armature or the bowl clamp nuts. The holes for these bolts are blind; therefore if the bolt bottoms out, it will seem to be tight when it is actually not. This situation will cause false reading in the tuning process.

Another factor that effects tuning is the stretching of the bolts that fasten the springs. Use grade "5" bolts, which are specifically hardened for durability to prevent this from occurring.

The tuning of a base drive unit is affected when a weld is either broken or cracked any place in the drive unit or:

- The mounting flange of the bowl;
- The track or skirts;
- The bottom of the return pan;
- The braces, pan wall, discharge area (as a general rule, these conditions will create a foreign noise and be easily detected).

Another condition that occasionally develops and is very difficult to detect, is bolts that hold the rubber feet onto the base drive backing out, causing solid contact between the drive unit and the mounting surface. This can cause the tuning to be misread. To check for this condition, remove the unit from the common base plate, and lift it up so that the feet are exposed and tighten the mounting screws.

It is very important that the clamp nuts holding the bowl to the base drive are tight. When re-mounting or re-locating a bowl on a base drive unit, use a torque wrench. In addition, never pull a bowl out, even slightly, from the clamp nuts to line it up with an existing track.

Alternatively, use the jackscrews (for levelling and height adjustment) which are built into must drive units as a standard feature. If the bowl is not level, parts may fall off or drift from the track prior to entering a selector causing track jams, disoriented parts and a loss of feed rate. A feeder must be level in order to maintain proper feed motion. Another problem can result by omitting the thin shim (spring spacer) between the springs when they are changed or added. These spacer shims are very important. If one is omitted, it will result in an adverse effect on tuning. If a shim is not available, one should be made and installed. Do not take the easy way out and try to get by without it. This will only cause more problems later.

The feed rate will be affected if all bolts that attach the rubber feet to the mounting plate are not securely located. These bowls are to prevent the units from rotating on the plate. When the drive unit is securely mounted to the plate, optimum feed motion will be transferred to the vibratory bowl.

Also, make sure that the holes are drilled on centre and the rubber feet are not stretched when tightened. This will prevent tuning problems.

If the gravity or inline track is connected to the vibratory bowl, the feed motion will be adversely affected.

The solution is to use an independent track to move the parts from the bowl discharge. If a feeder bowl has "dead spots", most often, the problem can be found by looking 180 degrees from the location of these "dead spots". As a general rule, mass has been added without counter-balancing the bowl, the gap in the coil has been improperly set, there is a broken weld, broken spring, or a loose spring bolt. Any of these conditions may contribute to the problem.

INTRODUCTION TO STEPPING MOTORS

Driving Techniques

The two most popular driving techniques are constant voltage and constant current; the former is usually employed with unipolar motors, the latter with bipolar motors but these divides are not necessary.

Constant Voltage Drive. In this configuration the motor is driven from a supply equal to the specified voltage for the motor and the performance is limited. The torque speed curve starts to decline at fairly modest speeds due to the back emf generated by the motor, and due also to the fact that the winding has a finite inductance ,L. In conjunction with the winding resistance this implies a time constant (=L/R) which inhibits the rise of current into the coil at higher frequencies leading to a reduction in torque. The time constant can be artificially reduced by adding external resistance and increasing the drive voltage accordingly. The nett result of this is that the high speed performance is enhanced, but at the expense of extra heat dissipated in the external (or forcing) resistance. Such a drive is then referred to as an L/R drive, and the value of the external resistance is usually indicated on the torque speed characteristics.

Constant Current Drive. In this mode the effect of the back emf and of the time constant associated with the coil are minimised by driving the motor from a much higher voltage than it is rated at – typically 40V and possibly as much as 100V for a 2V motor.

power on, the current through the winding starts to ramp up very quickly but is monitored by a current sensing resistor; when the current exceeds the rated value the supply is switched off for a predetermined time. At the end of this time the circuit reviews the current again and, if it is below the rated value, the supply is enabled i.e. switched on again. Substantial improvements in high speed performance can be achieved leading to increases in output power levels of as much as a factor of ten.

Unipolar stepping motors are provided with a centre tap on each of the two windings (or phases) The magnetic field can then be reversed by switching either of the two ends of the winding on, the centre tap being permanently connected to one side of the supply. Unipolar motors usually have six leads (but it is not unknown for the two centre taps to be internally joined resulting in a five lead motor). The unipolar motor is easier to drive because only four switches are required; the disadvantage is that at any one instant in time only half of the winding is being utilised, reducing the torque available.

Switching Sequences

The switching sequence defines the energisation patterns necessary on the windings to achieve controlled rotational movement. All the motors described can be driven in one of three basic ways – one phase on, two phases on, or one/two phases on – and the switching sequence for a size 23 is shown in the following pages.

One Phase on. This is sometimes referred to as wave drive. As the title suggests , only one phase is energised at any one time. Power consumption is low but the damping is small and noise can be a problem. However this configuration does offer the highest efficiency which may be significant if battery life has to be considered.

Two Phases on (full stepping) Two phases are always excited giving maximum output torque, but the motor can be subject to resonant bands.

One/Two phases on. Sometimes referred to as half stepping this is, as the title implies, a cross between the first two. The step angle is halved and resonance is minimised. Torque ripple occurs due to the variation in the M.M.F between one phase on and two phases on; however this can be reduced by overdriving during the one phase on condition, and some bipolar drive chips incorporate this function as a standard feature.

Microstepping. In this mode the currents in the windings are progressively increased/decreased electronically. This results in the rotor rotating in much smaller increments.

STEPPING MOTORS

Bipolar drive wiring diagram and switching sequence
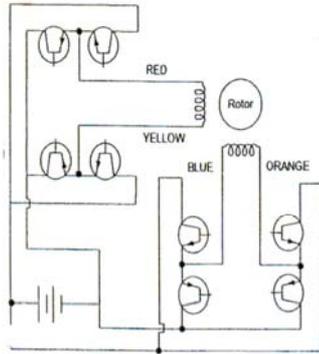
Unipolar drive wiring diagram and switching sequence
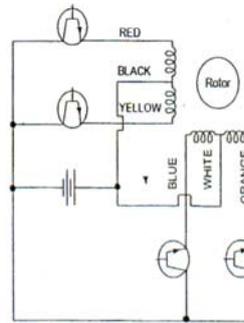
ONE-PHASE EXCITATION

STEP	RED	YELLOW	BLUE	ORANGE
1	+	-		
2			+	-
3	-	+		
4			-	+

ONE-PHASE EXCITATION

STEP	RED	YELLOW	BLUE	ORANGE
1	On	Off	Off	Off
2	Off	Off	On	Off
3	Off	On	Off	Off
4	Off	Off	Off	On

TWO-PHASE EXCITATION

STEP	RED	YELLOW	BLUE	ORANGE
1	+	-	-	+
2	+	-	+	-
3	-	+	+	-
4	-	+	-	+

TWO-PHASE EXCITATION

STEP	RED	YELLOW	BLUE	ORANGE
1	On	Off	On	Off
2	Off	On	On	Off
3	Off	On	Off	On
4	On	Off	Off	On

ONE, TWO-PHASE EXCITATION (HALF STEP)

STEP	RED	YELLOW	BLUE	ORANGE
1	+	-	-	+
2	+	-		
3	+	-	+	-
4			+	-
5	-	+	+	-
6	-	+		
7	-	+	-	+
8			-	+

ONE, TWO-PHASE EXCITATION (HALF STEP)

STEP	RED	YELLOW	BLUE	ORANGE
1	On	Off	On	Off
2	Off	Off	On	Off
3	Off	On	On	Off
4	Off	On	Off	Off
5	Off	On	Off	On
6	Off	Off	Off	On
7	On	Off	Off	On
8	On	Off	Off	Off

SIZE 23   HYBRID STEPPING MOTORS   M234118C632

Unit: mm

56.4
47.1
56.4
47.1

20.6
41
1.6
4.8
6.35Ø
38.1Ø
56.4Ø
11

5Ø mounting holes x 4

6 lead wire AWG 22 length 300mm
via connector on motor body
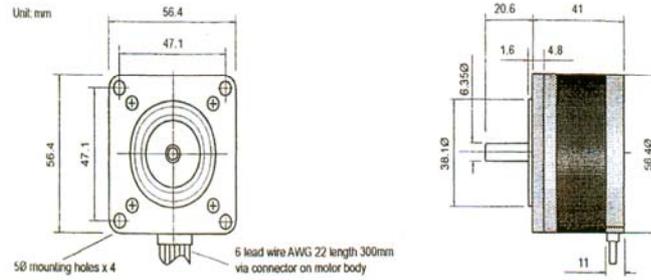
Model Number	Phase voltage V	Phase current A	Phase resistance Ω	Holding torque mNm	Phase inductance mH	Rotor inertia kgm³x10⁴	Detent torque mNm	Weight g	Winding
M234118C632	12.0	0.38	32.0	360.0	40.0	5.5	30.0	360	Uni-polar

General specification

Step angle	1.8°
Step accuracy	± 5%
Temperature rise	80°C (max)
Ambient temperature range	– 20°C to + 50°C
Insulation resistance	100MΩ (min) at 500V DC
Dielectric strength	500V AC 1 minute
Radial play	0.02mm (max) with 450g load

Full step uni-polar switching sequence

	BLUE	ORANGE	RED	YELLOW
Step 1	Off	On	Off	On
Step 2	Off	On	On	Off
Step 3	On	Off	On	Off
Step 4	On	Off	Off	On

Clockwise rotation

BLUE
WHITE   HS
ORANGE

RED   BLACK   YELLOW
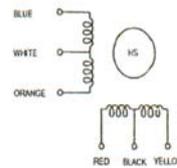
(Connect Black and White to positive supply)

Characteristics

Pull Out
Pull In

Torque mNm

| P.P.S. | 0 | 50 | 100 | 150 | 200 | 250 | 300 | 350 |
| R.P.M | 0 | 15 | 30 | 45 | 60 | 75 | 90 | 105 |

Speed

Test Conditions

Drive: 12V 0.38A/phase
SMO2 full step uni-polar drive.

Load inertia: 9.7 x 10⁶ Kgm²
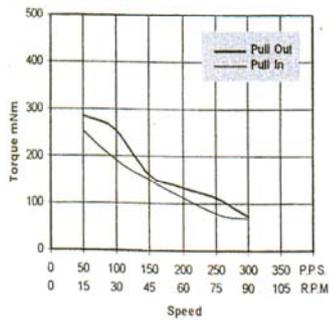
Design Study for a Range of Automated Orientation Tools

Introduction

The mechanical design and the development of mechanised and automated orientation tools was the critical first stage process in the development of a flexible VBF system. It was anticipated earlier in the project that the AMTLAB vibratory bowl feeder would eventually consist of a sufficient range of orientation tools to cover the feeding of a wide range of components. The development of the wiper blade tool was useful in demonstrating the issues of tool adjustability through programmability. The process of standardisation and implementation on this tool, established a firm basis for future tool development. Two further tools were developed as outlined in the previous chapter. Seven other orientation tools were designed with the intention of future tool development and implementation/inclusion into the AMTLAB vibratory bowl feeder system at a later stage. This chapter presents the design work on these seven tools which were as follows:

1. Step Down Tool
2. Hold Down Tool
3. Pressure Break Tool (Wall Projection Module)
4. Slotted Track Tool
5. Sloping Track (Roll Up Module)
6. Cut-Out Notch (Scallop Module)
7. V-Cut-Out Tool

The description of the conventional tool is presented first. This includes method of operation, functions, type (active or passive) and factors that affect component feed rate. The design data used in the development of these conventional tools (provided by Boothroyd [1981]) were then used here in the design of programmable tools, but were adapted for mechanisation. Concept models for each tool were developed to help visualize and demonstrate their programmable features. The dimensions of the actual tools would have to conform to the dimensions of the specific VBF used.

1.The Step Down Tool (Step Module)

A conventional step down orientation tool is effectively a recess step machined down into the vibratory bowl track. Its objective is to re-orientate components from a group

of components into a desired attitude, as the components are stepped down. The step height is arranged so that the orientation of components in orientation 'a' or 'c' are not affected as they pass by the step down tool (Fig. I-1). The step down tool is classed as an active orientation device actively reorienting components into the required orientation. It does not reject components back into the VBF. In the experimental orienting system shown the first device to be used is the active step down tool, the second is a cut-out-notch (scallop module) and the third is a sloping track tool (ledge module).
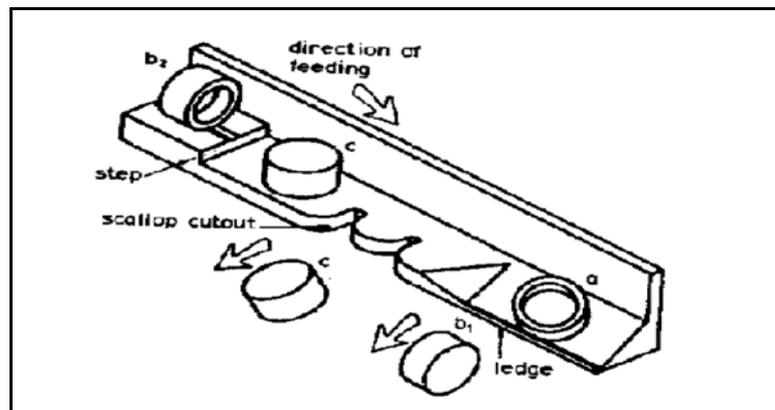
Fig. I-1: Experimental Orientation System (Boothroyd, 1981)

This system of tools clearly demonstrates that components in orientation 'a' only, will go through to the outlet of the VBF. The cut-out-notch and the sloping track tools serve to orientate the component into orientation 'a' by rejecting components in orientation 'b$_1$' and 'b$_2$'. The feed rate of correctly orientated components from this system will depend upon the rate of parts that encounter the system of tools and the number of components that successfully negotiate the orientation system in orientation 'a' only.

Design Data to Consider in the Development of a Programmable Step Down Tool
This tool is now considered for redesign as a programmable step down orienting tool. The new design should lead to the eventual development of the prototype tool (Prototype #1). The only orienting system variable considered here is the height (**h**) of the active step orienting device [Boothroyd, 1981]. The design of this tool is considered relatively simple as it involves the programmability of the stepping device only. It was envisaged that the step down tool would be designed so as to pivot on one side of the track as the other side is raised incrementally above the remaining part of the

track.   The step height required will be determined by obtaining the maximum delivered efficiency of the orientated components as they pass by the tool.   If the step height is set too low the components might not orientate properly as they land on the track below and this will render the tool ineffective.   If the step height is set too high the components may bounce erratically upon landing on the track below which would be unacceptable.   The other factors to consider in the design of the programmable step down tool are as follows:

1. The centre of gravity of the components being conveyed should be calculated in advance of the new design. This will ensure that its operating range is sufficient to perform the reorientation process.

2. The only part of the tool that should come in contact with the components is the step tool ledge section.

The Programmable Active Step Down Tool Concept Model

A step down tool design was developed based on the design constraints and the operation of the conventional tool as previously mentioned (Fig. I-2).
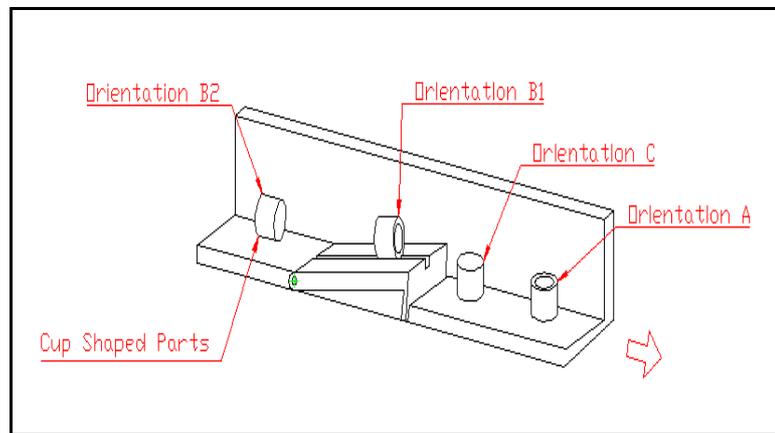
Fig. I-2: Design Concept for the Step Down Orientation Tool

The diagram shows a new design proposal for the orientation of cup-shaped components using an active step down orientation tool.   The step height (h) is made variable and can be raised or lowered as required as it pivots about the feeder track. This design was considered viable and resulted in the development of a 3D cardboard concept model.   The purpose of the 3D model was to demonstrate and evaluate the prototype design as a feasible solution towards its eventual development (Fig. I-3).
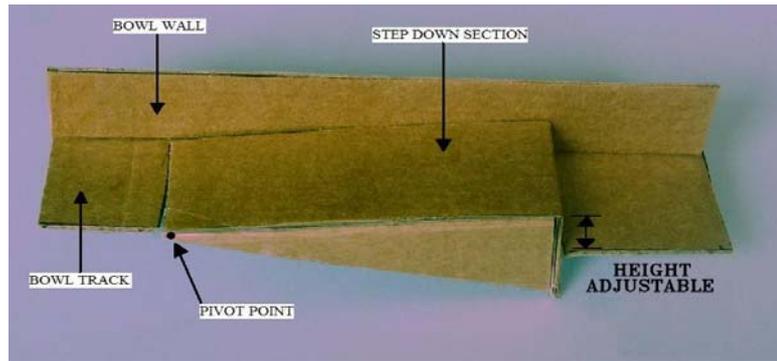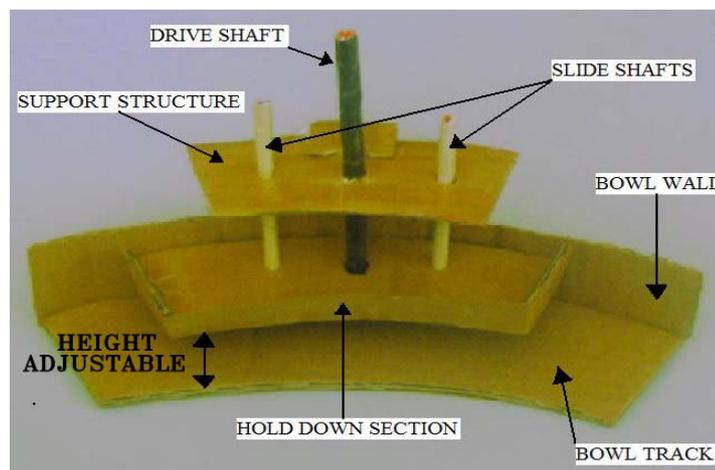
Fig. I.3: The Step Down Tool Concept Model

The concept model consists of an adjustable section of track that can be adjusted from beneath the track, raising or lowering the step height as required. The step down section pivots about a point in the bowl track. The movement of the track section could be performed by manual programming and if fitted with a stepper motor drive clutch system could be automated as before.

Design Functionality - This tool should work effectively if the components travelling up the incline section of track negotiate the climb without encountering component transfer problems. An alternative design proposal (Fig. I-4) is provided in this case. The alternative design uses a telescopically operated section of track to extend the length of the step down tool. As the length of the step down section is changed so too will the height. This might be achieved using a linear slide and a screw thread mechanism mounted from beneath the track and driven using the now standardised stepper motor drive clutch system as before.

Technical Feasibility - A stepper motor drive system could be used through a mechanical assembly to raise the height of the step. In that case a screw tread section could be rotated from beneath the track that will extend linearly and provide incremental steps as required.
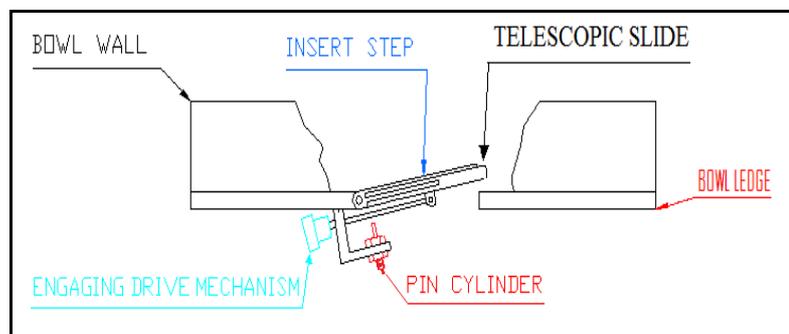
Fig. I-4: Change the Length of the Step Down Track (Telescopically)
Operation of the Programmable Step Module Tool (Height Change Only)

The operation of this tool should proved relatively simple (Fig. I-5). Adjusting the stepping motors position through a controlled rotation, provides incremental height changes through the threaded shaft mechanism (Fig. I-6) In effect rotary motion is transferred into linear motion of the active step tool. When this has been achieved a pin cylinder will lock the raising mechanism (threaded shaft and collar) in the new position and prevent motion while the vibratory bowl feeder is operating.
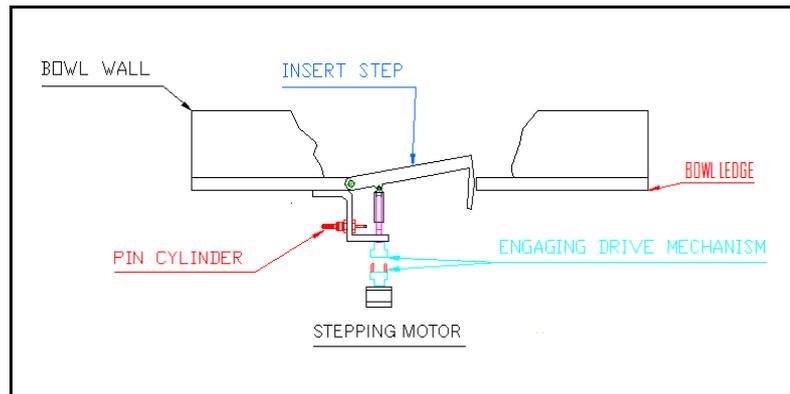
Fig. I-5: Front View of the Programmable Step Down Tool

The dimensions of the prototype tool will depend upon the dimensions of the vibratory bowl feeder and the dimensions of the components used.
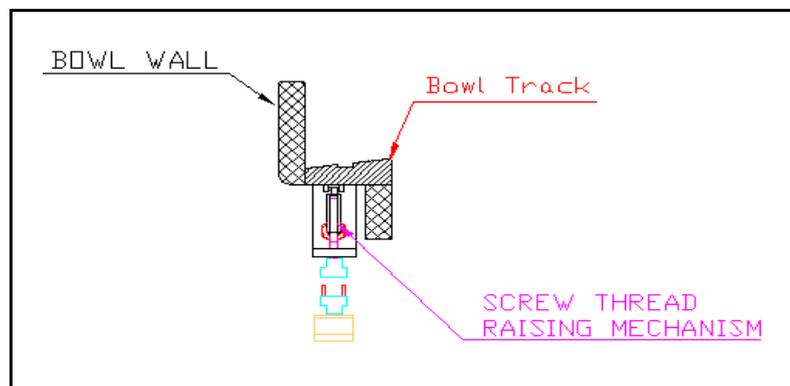
Fig. I-6: Side View showing the Threaded Shaft Raising Mechanism

The most efficient position of the tool will be found when the objective of maximising the number of components in orientation 'a' is achieved. This may be achieved when a step height that does not adversely affect many of the components in orientation 'a', but reorients some of the components in orientation 'b_1' or 'c' into orientation 'a', as they pass over the step.

Design Discussion

This tool should perform effectively for various step heights. The step tool is inclined

at an angle to the bowl track. It can be adjusted rotationally (varying the height) as it pivots about a central point (pivot point). Problems could occur if components experience a sudden change in the track angle.   Increasing the length of the active step tool while reducing the angle of inclination between the track and the step tool while simultaneously maintaining the step height.   This should promote a smooth translation for components as they are conveyed from the VBF track onto the step tool ledge.   Fig. 5-4, provided an alternative design solution to help solve this problem.

In the case of cup shaped components mentioned previously, reorientation into the required orientation will depend on the component dimensions.   Component dimensions of length and diameter are important to determine its centre of gravity.   The step down tool works on the principle of changing the orientation of a component by changing its centre of gravity from a stable equilibrium position to an unstable equilibrium position as the components fall from the step.   This should provide an accurate estimate to determine the step height.

Component Ranges

The step down tool should be design to maximise its component range by maximising its operating range for various step heights (**h**). A possible operating range for the height (γ) is from 0mm to the height of the bowl wall as it pivots about its pivot point. The AMTLAB step down tool (Prototype #1) should have a component operating range as follows:

- Component   *height* is limited as follows:
    - A maximum height does not apply (i.e. A practical limit might be the height of the bowl above the track or possible the tool slide under-clearance).
    - A minimum height of say 5mm should apply. This limit applies to the practicality of feeding   and selecting/orienting small components
- Component   *diameter* (width) is limited as follows:
    - A maximum diameter applies of 24mm (i.e. The track width).
    - A minimum diameter of say 5mm should apply. This limit applies to the practicality of feeding   and selecting/orienting small components

2   The Hold Down Tool

The hold down tool is a device used to secure previously orientated components on the bowl track (or rail) by maintaining component orientation over a sufficient length of

bowl track. A hold down tool is usually positioned near the outlet of the VBF but could be used between tools to maintain orientation if required. The conventional hold down tool has a similar shaped track to that of the bowl track and is usually made of the same material as the bowl. The tool is attached horizontally to the bowl wall and set at a height above the bowl track. The tool is classed as a active orientation device as it does not reject components back into the vibratory bowl (Fig. I-7).
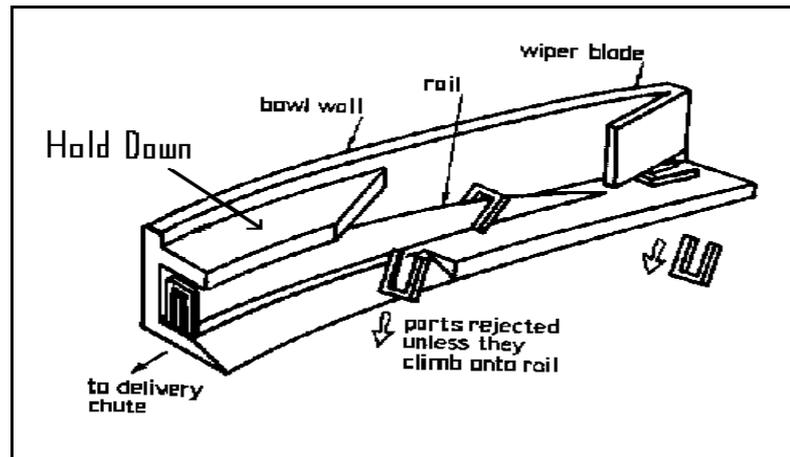
Fig. I-7: Orientation of U-Shaped Components in a VBF (Boothroyd, 1981)

The orientation system developed for the handling of U-shaped components in a VBF demonstrates the function of the hold down tool. The wiper blade tool and the climbing rail tool are used to filter out an upright orientation of the component (the upright   U-shaped components in the case of the latter) of the component. The hold down tool is used to secure the vertically down U-shaped components on the rail [Boothroyd, 1981]. The distance set between the hold down tool and the rail section is important to maintain orientation. The efficiency of the tool will depend on the number of components that encounter the tool in the correct orientation and the number of components that maintain orientation as they pass by the tool. An effective hold down tool should promote an unrestricted feed rate of correctly orientated components to the delivery chute.

Factors to Consider in the Design of a Programmable Hold Down Tool

The hold down tool will now be considered for redesign as a programmable tool. This is the first stage in the development of a prototype tool (Prototype #1). The only orientation system variable considered here is the height (**h**) of the hold down tool above the rail (or track). If the height of the tool is set too high the components are

likely to vibrate excessively and change orientation. This would be unacceptable in practice. If the height is set too low components may become trapped and this would result in a blockage at the tool location. A programmable hold down tool should be controlled over various heights. The other factors considered important in the design of the programmable hold down tool were as follows:

1. The only part of the tool that should come in contact with the components is the hold down section. Constant contact between the components and the tool should be avoided as this could result in unsteady transfer motion.

2. The hold down section of the programmable tool should be mounted clear of the bowl wall to provide adequate clearance for unrestricted operation of the hold down section.

3. The tool should be designed so that it is held in a stable position on the bowl track when the VBF is operating.

The Programmable Hold Down Tool Concept Model

A concept model (Fig. I-8) was designed. This was based on numerous design sketches. The final design was developed with the aid of specially constructed 3D cardboard model as before. The purpose of the 3D model was to demonstrate and evaluate the prototype design as a viable solution towards programmability.

Fig. I-8:   The Hold Down Tool Concept Model

The concept model consists of a hold down section, slide shafts, and a support structure for the mechanical assembly. The tool should be attached to a mechanical assembly that is supported from outside the bowl wall. Two locating slide shafts provide a rigid guide for the hold down section as it is moved vertically producing various height (**h**)

changes above the track.

Design Functionality - The hold down section of the tool is no longer rigidly attached to the bowl wall.   This might result in excessive vibration of the hold down section.   The two locating slides are provided to help guide the hold down section while providing tool   rigidity in an attempt to reduce vibration transmission.

Technical Feasibility -   This tool could be developed and manufactured as an assembly completely independent of the vibratory bowl feeder and reattached at a later stage in the desired location.   This provides the tool with a certain level of inter-changeability and modularity.   To automate the tool it should be adapted with a clutch coupling that would be driven by the standardised stepper motor drive system as before.

Operation of the Programmable Hold Down Tool

The hold down section of the tool was designed to move vertically producing various heights configurations above the bowl track.   The drawings provided demonstrate the mechanical makeup of the programmable hold down tool (Fig. I-9).
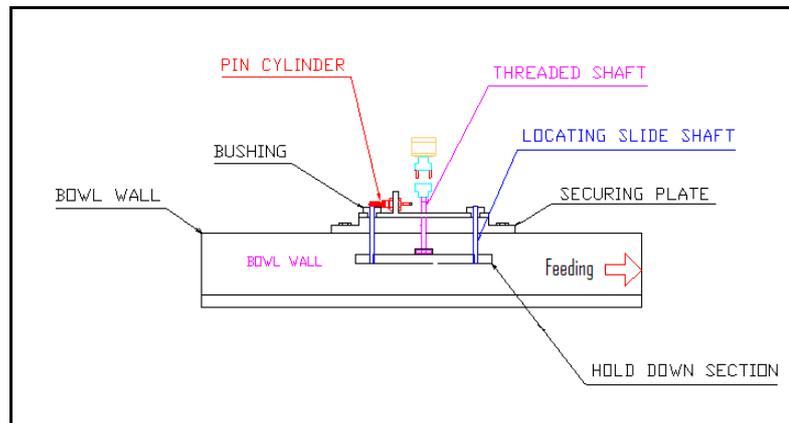
Fig. I-9: Front View of the Programmable Hold Down Tool

The mechanical assembly is attached to the bowl wall using a securing plate and bolts. Two locating slide shafts, provided with bushings, guide the hold down section in a horizontal position above the components.   When the stepping motor is engage and rotated clockwise the height of the hold down tool changes and moves closer to the bowl track (Fig. I-10).   This allows thin components to be conveyed between the hold down section and the track.   Anticlockwise rotation moves the tool away from the bowl track allowing thicker components to be accommodated.   After each height change, the stepping motor is disengaged from the tool and the tools position is securely fixed using a carefully positioned pin cylinder.
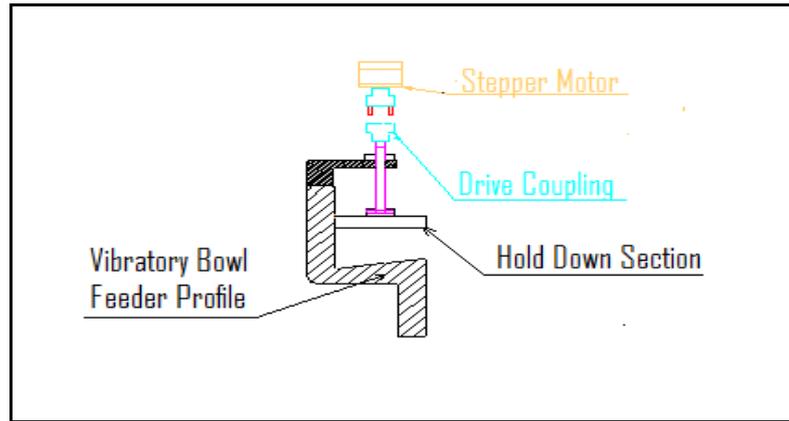
Fig. I-10: Sectional View of the Hold Down Tool

This tool can be experimented with for various components having different shapes and sizes.

Design Discussion

This tool should function adequately if the bushings and the locating slide shafts are designed to a close tolerance. This will help to maintain the hold down section in position at a any specific height (**h**).   The effects of vibration on the tool should also be considered.   As the hold down section of the tool moves away from its securing plate and approaches the bowl track excessive vibration may occur in the hold down section. This could arise due to the mass of the hold down section acting at some distance from the securing plate. To prevent this, the hold down section should consist of a light material such as aluminium and the diameter of the locating shafts should be as large as practical to aid tool rigidity.

Component Ranges

The hold down tool will effectively maximise its component range by arranging for the maximum adjustable height (**h**). The possible operating range for the hold down section is from 0mm (lying flat on the track) to the height of the bowl wall.   The AMTLAB hold down tool (Prototype #1) should have a component operating range as follows:

- Component   *height* is limited as follows:
  - A maximum height does not apply (i.e. A practical limit might be the height of the bowl wall above the track, or possible, the tool slide under-clearance).
  - A minimum height of say 2mm to 3mm should apply. This limit applies to the

practicality of feeding   and selecting/orienting small components

- Component **width** (diameter) is limited as follows:

    - A maximum diameter of 24mm applies (i.e. track width)

    - A minimum diameter of say 5mm should apply. This limit applies to the practicality of feeding   and selecting/orienting small components

3 The Pressure Break Tool (Wall Projection Module)

The pressure break tool is the second device to be encountered by the screws in the orientation system (Fig. I-11) below.   The conventional tool is a V-shaped profile section of bowl material that is attached to the bowl wall and projects outwards onto the bowl track.   The tool reduces the track width at that point.   A pressure break tool functions as a passive orienting device that rejects components in an undesired orientation back into the VBF.
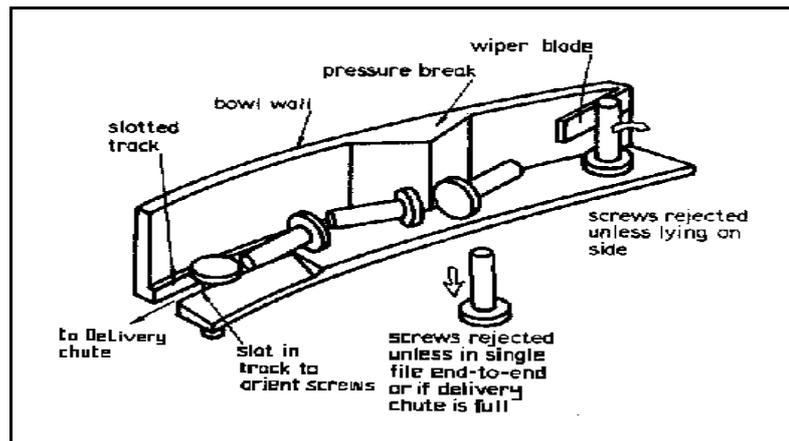
Fig. I-11: Orientation of Screws in a VBF (Boothroyd, 1981)

It is a very versatile tool and performs more that one function.   Arguably its most important function would be to reject components completely when the delivery chute becomes full.   Therefore it breaks the pressure on queued components by directing all orientations of that component back into the bowl until the assembly machine has shifted this queue.   The location of this tool will be essential in obtaining its maximum performance.   The pressure break tool also acts as a separation device as it only allows components to pass by if they are in a single file and with either the head or shank leading [Boothroyd, 1981].   Therefore the tool allows through only components with a certain attitude.

Design Data Consider in the Development of a Programmable Pressure Break Tool

Boothroyd, does not provide design data for the development of this tool. It is considered by the author that the following two design parameters should be considered important in the design of a pressure break tool. The most important design parameter would be the distance (**d**) obtained between the apex of the tool and the edge of the bowl track. This will dictate an acceptable distance for components obtaining the correct attitude. Other design data to consider might be the included half angle of the V-shaped profile (θ). This controls the angle formed between the bowl wall and the side of the pressure break tool. The Angle (θ) should be programmable to promote a smooth flow of components past the tool and on to the delivery chute (Fig. I-12).
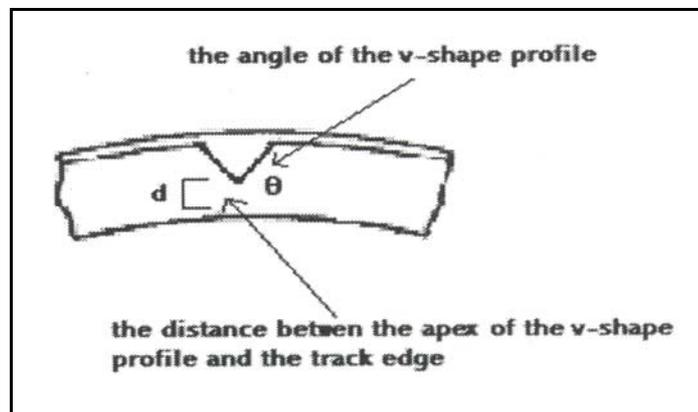
**Fig. I-12: Data to be considered in the Design of a Pressure Break Tool
(adapted from Boothroyd, 1981)**

Factors to Consider in the Design of the Programmable Pressure Break Tool

Design factors and parameters that are considered important for the design are as follows:

- The only part of the tool that should come in contact with the components is the pressure brake tool projected surfaces.

- A requirement of the tool design is a programmable half angle (θ) 'ideally' controlled between an angle 0° to an angle 45°. This will help to cater for a wide range of components.

- The distance (**d**) from the track edge to the apex of the V-shaped profile should be programmable from 0mm to 24mm (i.e. the track width).

The Programmable Pressure Break Tool Concept Model

A concept model was designed that was based on numerous design sketches. A final

design was developed with the aid of specially constructed 3D cardboard model (Fig. I-13). The purpose of the 3D model was to demonstrate and evaluate the prototype design as a viable solution towards programmability of the conventional tool.
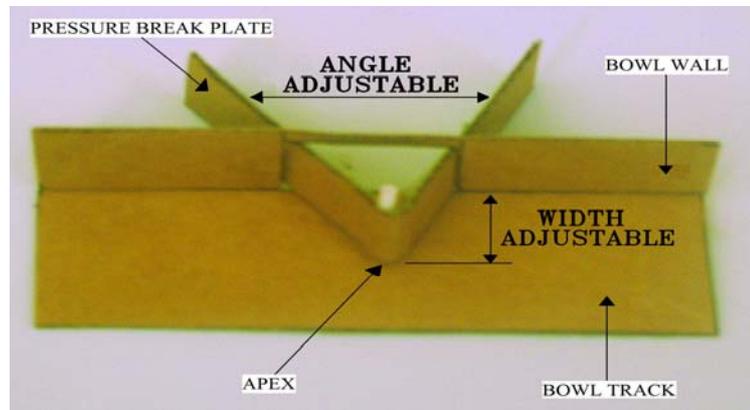
Fig. I-13:   The Pressure Break Tool Concept Model

The concept model consists of a width and angle adjustable wall section. When developed, the tool will be programmable producing various width and angle configurations.

Design Functionality - The components must negotiate the points of contact between the bowl wall and the pressure break tool. Where these points occur the probability of unsteady transfer movement will increases and could possibly result in unintentional reorientation or blockages. If this situation occurs, one possible solution might be to use rubber seals at these locations to assist in the smooth transfer of components past these points.

Technical Feasibility - The feasibility of developing a working tool without incurring component transfer problems is difficult to envisaged. The difficulty in controlling the mechanical movement of the pressure break tool around two variables of width and angle configurations could prove problematic. One possible solution is the acceptance of a non-symmetrical brake plate: a controlled angle and depth on the input side but uncontrolled on the output side (Fig. I-14).
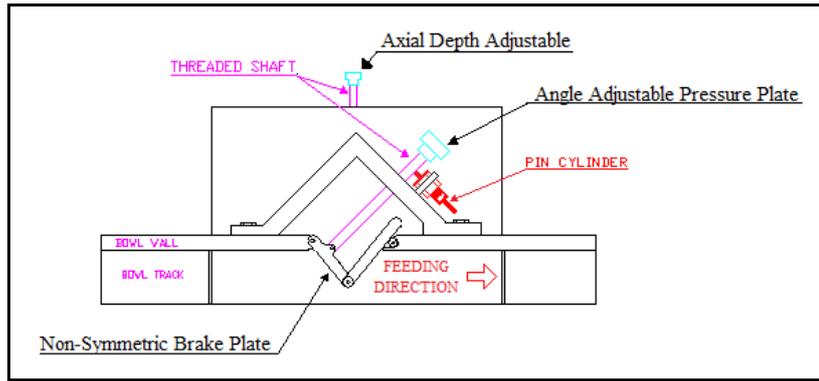
Fig. I-14: The Design of an Asymmetrical Brake Plate System

For the purpose of this project it is assumed that a compromise can be achieved between angle and depth which will be acceptable with the simple symmetric arrangement. The two movements of angle and depth could be programmed using the standardised stepper motor drive system similar to that demonstrated by the wiper blade tool (section 4.4.2).

Operation of the Programmable Pressure Break Tool
The design concept consists of a combination of mechanical parts (Fig. I-15). Having demonstrated the concept model, drawings were produced for the design of the programmable tool (Prototype #1).
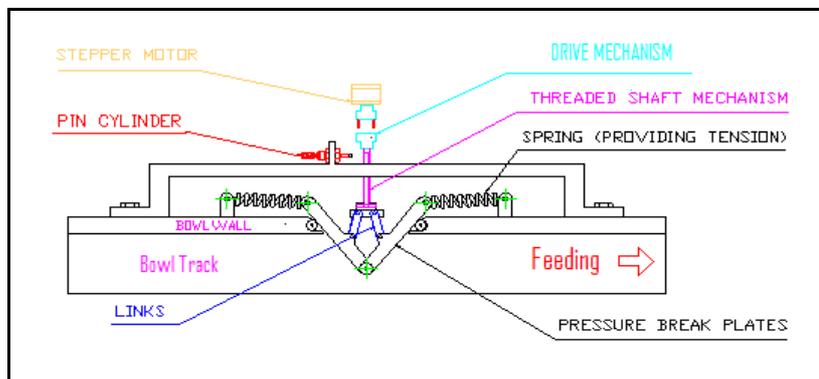
Fig. I-15: Plan View of a Programmable Pressure Break Tool

Two pressure break plates are joined at the apex and mechanically linked through a linkage system that pivots (varying the half angle) at the tip. These plates combine to form a single pressure break tool that looks like the conventional tool (Fig. I-16). The width between the pressure break apex and the track edge can be adjusted simply, via a stepping motor through a threaded shaft mechanism and the linkage system. Clockwise rotation extends the threaded shaft and reduces the width while anticlockwise rotation retracts the treaded shaft increasing the width. After each

setting the position of the tool is locked in position by a carefully positioned pin
cylinder.
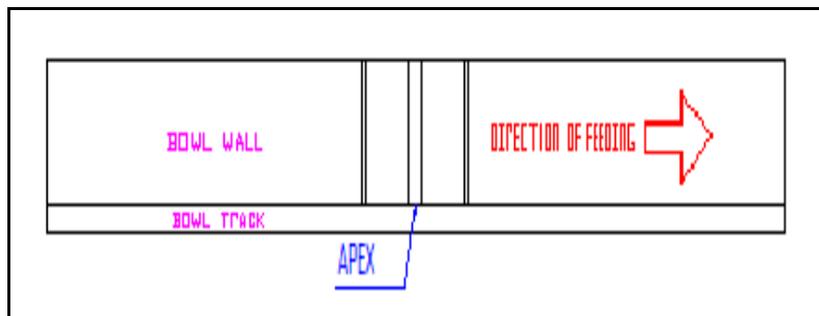
Fig. I-16: Front View of a Programmable Pressure Break Tool

The tension springs serve two functions, firstly they act uniformly on the pressure break
plates, this will help to maintain tool rigidity while the VBF is vibrating. Secondly
they help to apply pressure on the pressure break plates forcing them to maintain
constant contact with the bowl wall. Arguably the second function is the most important
because by maintaining constant contact with the bowl wall, as the stepper motor is
rotated, the half angle is adjusted accordingly via the linkage system. As the width
between the bowl edge and the apex of the pressure break tool is reduced the half angle
is also reduced. As the width is increased the half angle will be increased.   This means
that the stepper motor controls both the width and angle configurations of the tool at the
same time because one configuration dimension is relative to the other.   Small rollers
fitted in the bowl wall should assist in a smooth action of this mechanical motion.
Maintaining contact between the bowl sides and the pressure break plates should
promote a smooth flow of components passing by the tool.   It will also ensure that no
gap appears between the bowl wall and pressure plates that would inevitably lead to
feeding problems.

Design Discussion

This tool was designed to fit onto the AMTLAB vibratory bowl feeder wall as a tailored
fixture.   To arrange for inter-changeability it should be possible to design and develop
a tool that fits onto a replaceable section of bowl track.   The asymmetric pressure plate
system suggested earlier would require two separate movements (involving two motors)
but might prove more successful in terms of component feeding as the two variables of
angle and depth are controlled independently.

Component Range

The operating range of the pressure break tool is determined by the width and angle configurations. The programmable tool design concept uses the width of the track as a guide to provide a minimum and maximum distance: 0mm at the edge of the track increasing to 24mm at the bowl wall.

- Component **width** is limited as follows:

    The width is programmable from the bowl wall (0mm) to the edge of the VBF, hence a maximum distance of 24mm applies (i.e. track width)

    A minimum width does not apply (however the practicalities of feeding small components would give rise to a minimum diameter of say 5mm)

- Component **height** is limited as follows:

    Unlimited on height (a practical limit might be the height of the bowl above the track or possible the tool slide under-clearance).

4   The Slotted Track Tool

A slotted track tool is a device used to re-orientate components that have both a shank and a head. The conventional tool (Fig. I-17) consists of a machined slot in the bowl track located near the delivery chute. Items typically used with this type of tool are long/short bolts, screws and rivets etc. The slotted track tool functions as an active orientation device actively reorienting the components into the desired orientation.
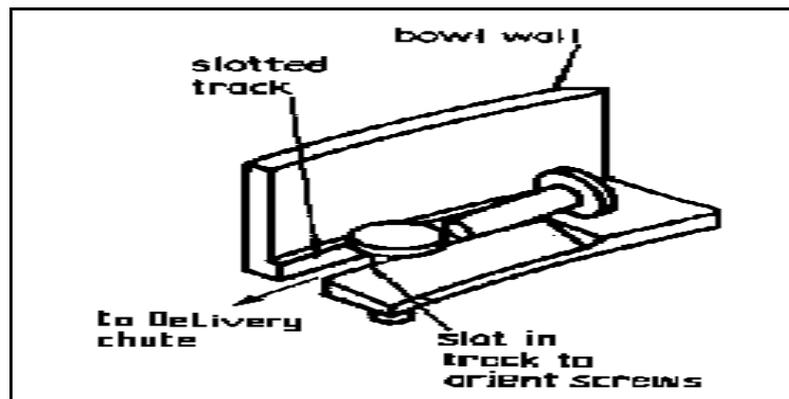
Fig. I-17: The Slotted Track Tool (adapted from Boothroyd, 1981)

In the case of screw shaped components, the desired orientation is with the head supported and the shank hanging. The location of the slot for machining can be determined by using the dimensions of the component to be conveyed. The dimensions to consider are the diameter of the head and the diameter of the shank. It is also

important to know the position of the centre of gravity of the component being conveyed.

Design Data Considered in the Development of a Programmable Slotted Track Tool

Boothroyd briefly discusses the functions of the slotted track tool but does not provide design data considered essential for its development. Having researched the tools functions it is considered by the author that the Width (W_s) of the slot in the track should be programmable. The width of the slot should be sufficiently wide to allow the shank of the screw to fall through while retaining the screw head. Other design data to consider would be the Distance (**D**) between the bowl wall and the centre line of the slot, as this determines the largest diameter head. It is important to make both of these dimensions (Fig. I-18) programmable in the new design; this should help to accommodate components with different dimensions.
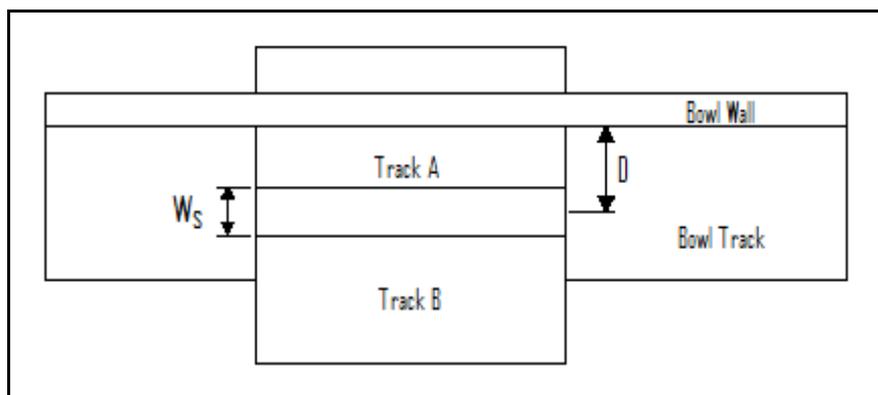
Fig. I-18: Data to be Considered in the Design of a Slotted Track Tool

Factors to Considered in the Design of a Programmable Slotted Track Tool

The following design factors and parameters were considered important for the design of a programmable slotted track tool:

- The only part of the tool that should come in contact with the components is the programmable track sections.
- A requirement of the tool design is a programmable slotted track width. Ideally the width should be controlled to accommodate all situations for various headed components within certain dimensional parameters. In this situation the width will be programmable from between 0mm (closed position of the tool) to 24mm (i.e. the track width).
- The Distance (D) between the centre line of the slotted track and the VBF wall

could be programmable from between 0mm (fully retracted position) to a
maximum of 24mm the track width (fully extended position).

- The length of the slotted track should be sufficient to complete the reorientation
process and provide an adequate number of queued components for delivery to the
assembly machine.

The points mentioned above are considered important for effective tool operation.

The Programmable Slotted Track Tool Concept Model

Again a concept design was developed based on a number of design sketches. A final
design was developed with the aid of specially constructed 3D cardboard model
(Fig. I-19). The purpose of the 3D model was to demonstrate and evaluate the
prototype design as a viable solution of the programmability of the conventional tool.
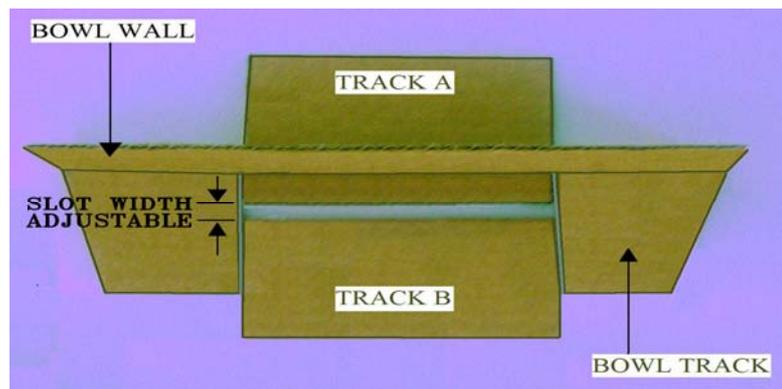
Fig. I-19: The Slotted Track Tool Concept Model

The concept model consists of two programmable sections of bowl track that can be
controlled intermittently and independently. This should produce various slot and track
width configurations to suit a wide range of components.

Design Functionality - This tool should function effectively for various headed
components. The components will have to negotiate a small gap in the track as they
are conveyed from the bowl track onto the slotted track; this is where the programmable
tracks and bowl track merge. This could cause unsteady transfer motion and possibly
result in unintentional reorientation. If this situation occurs one possible solution to the
problem might be to lower the tracks of the tool by say 0.1mm to provide a small step
down this will promote a smooth conveying action across the tool.

Technical Feasibility - The design and development of this tool could prove
complicated and problematic as it will involve the programmability of two track

sections that are controlled intermittently and independently, however it appears very feasible.

Operation of the Programmable Slotted Track Tool

Having demonstrated the concept model, drawings were produced for the design of the prototype tool (Prototype #1), (Fig. I-20 & Fig. I-21)
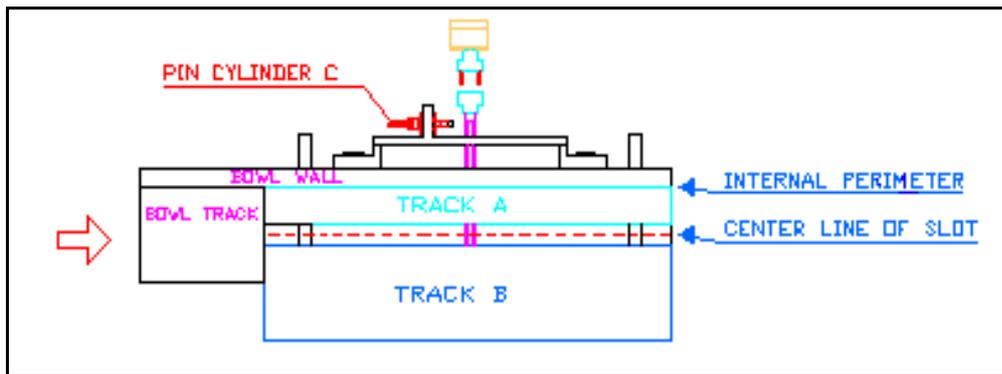
Fig. I-20: Plan View of the Programmable Slotted Track Tool

The slotted track tool consists of two sliding tracks, Track A and Track B that allow the slotted distance between them to be varied to accommodate various shank diameters.
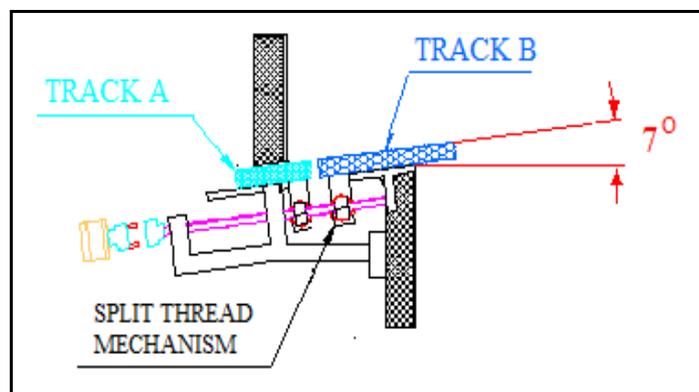
Fig. I-21: Side View of the Programmable Slotted Track Tool

One additional benefit of adjusting two tracks is that the Distance (D) between the centre line of the slot and the bowl wall (internal perimeter) is also variable. This accommodates dimensional changes in the diameter of the component heads. Fig. I-21 shows the exact location of the tracks and demonstrates the mechanical makeup of the assembly. The tool accommodates a positive track angle of 7° to coincide with the bowl profile. To explain how each track moves it is considered important to understand how the engaging and disengaging mechanisms (Split thread link) operates.
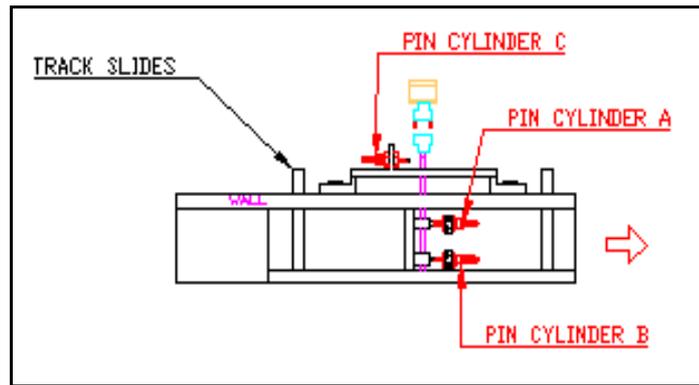
Fig. I-22: The Programmable Slotted Track Tool, Tracks Removed

The pin cylinders (Fig. I-22) that are attached to the underside of the tracks perform two main functions:

- The pin cylinders are required to operate the engaging and disengaging links. Each pin cylinder can be operated independently. This provides the individual track movements.

- When the VBF is operating the pin cylinders are used to lock the tracks in their respective positions.

Fig. I-23 shows a pin cylinder acting on the thread shaft link. This should perform the engaging and disengaging procedures.
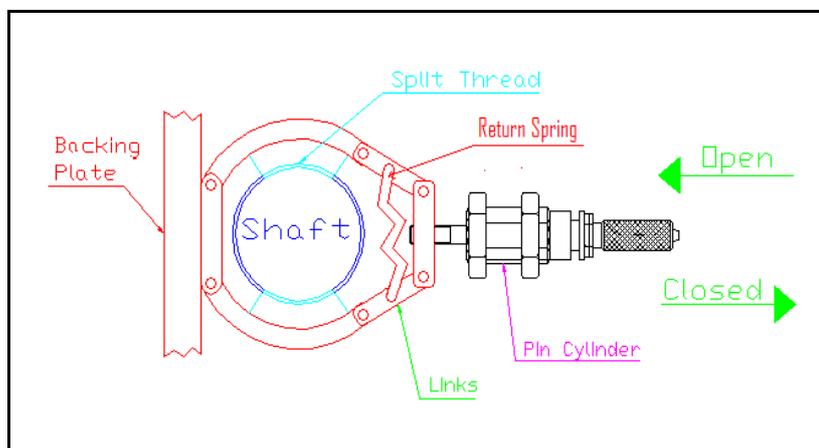
Fig. I-23: Split Thread Mechanism with the Pin Cylinder Attached

As the pin cylinder is extended the device is forced against the backing plate. This restricts its movement about the X-axis. When the pin cylinder is operated the applied pressure forces the split link thread to open evenly from the threaded shaft. This prevents Track A, attached to the pin Cylinder A, from moving any further. When the pin cylinder is retracted assisted by the spring the split thread link mechanism engages with the drive shaft and the drive will again be connected to the individual tracks as

before.   The track slides are used to provide rigidity and assist in the sliding action of
the track movements.   The pin Cylinder C is provided to prevent vibration during the
operation of the VBF.

Design Discussion

This tool has not yet been manufactured and it is difficult to see if it would actually
work efficiently.   However the idea of using two tracks that act independently that can
be controlled intermittently is an essential design feature to consider if a variety of
components are to be accommodated.   This means that headed components with
different dimensions can be experimented with automatically in sequence to determine
the tools optimum position in relation to each specific component.   The manufacturing
of such devices as the engaging and disengaging mechanism could prove difficult, as
these devices will be small.   Prior to the development and manufacture of this tool a
split thread linkage mechanism should be manufactured and demonstrated as a working
device.

Component Range

The slotted track tool was designed to accommodate various headed components.   The
tool design concept uses the width of the track as a guide to provide a minimum and
maximum operating range.

- Component ***Diameter*** (Shank) is limited as follows:

    The slot width is programmable from the bowl wall (0mm) to the edge of
    the   VBF.   Hence a maximum distance of 24mm applies (i.e. track width).

- Component ***Diameter*** (Head) is limited as follows:

    A practical limit for the head of the component might be the height of the
    bowl above the track and/or the radius of the head to a maximum of 24mm
    (i.e. track width).

5   *The Sloping Track Tool (Ledge Module)*

A sloping track tool is a device used to reduce the number of orientations of a
component to one orientation only, the desired orientation.   The conventional tool
(Fig. I-24)   consists of a proportion of track that slopes sideways and downwards to
create a negative track angle aiming towards the centre of the bowl.   The ledge is
provided to retain washers that are lying flat and in single file.   Items typically used

with this type of tool are washers, truncated components, single sided bevelled nuts and components with steps or groves etc.
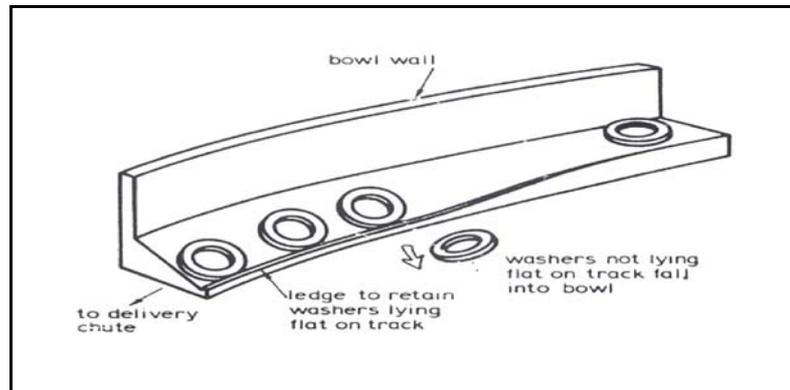
Fig. I-24: Orientation of Washers in a VBF (Boothroyd, 1981)

The sloping track tool functions as a passive orientation device that continually rejects components back into the bowl for recirculation, if the components do not possess a hanging attitude or sit comfortably on the retaining ledge.   The feed rate of components that pass by the sloping track tool will depend on the number of components that encounter the tool, the number of components that are not in single file and the number of components that do not posses a hanging attitude.

Design Data Considered in the Development of a Programmable Sloping Track Tool

Boothroyd, briefly discusses the functions of the slotted track tool but does not provide the essential design data required for its development.   It was initially considered by the author, having researched the functions of the sloping track tool, that the following design data should be considered important in the design of a programmable sloping track tool: the included Angle (θ) made between the sloping track tool and the normal angle of elevation of the VBF track (Fig. I-25), the Height (H) of the retaining ledge and possibly its shape.
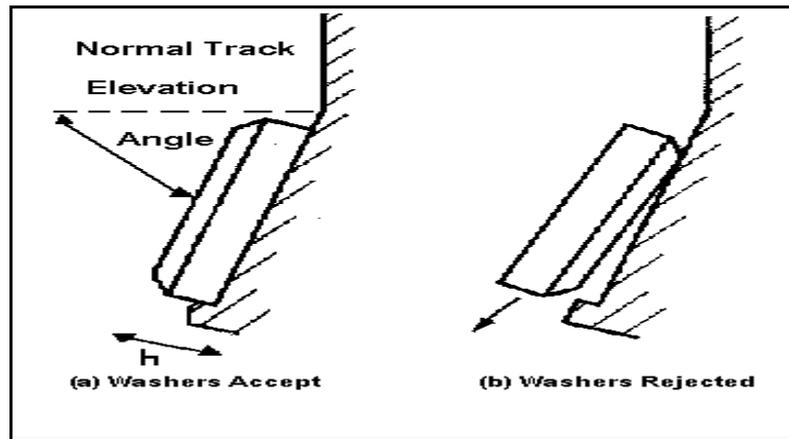
**Fig. I-25: Data to be Considered in the Design of the Sloping Track Tool
(adapted from Boothroyd, 1981)**

Factors to Consider in the Design of a Programmable Sloping Track Tool

The following design factors and parameters were subsequently considered important in the design of a programmable sloping track tool:

- The tool should be designed to turn the components gradually as they are conveyed over a sufficient length of bowl track. The centre of gravity of the component should not be raised rapidly [Boothroyd, 1981]. Otherwise the feed rate could be seriously affected.

- To cater for a wide range of components, the included angle should have a maximum operating range from 0° and 90°.

- A sufficient number of retaining ledges of various sizes and shapes should be provided. These ledges could be manual programmable attachments for the sloping track tool that are locked in position by manual screw adjustment only.

The Programmable Slopping Track Tool Concept Model

As before a design concept was developed based on a number of design sketches. The final design was developed with the aid of a specially constructed 3D cardboard model (Fig. I-26). The concept model consists of a programmable sloping track section that can be controlled from underneath via a linkage mechanism and is raised or lowered as required. This will produce various negative angles for the sloping track section. A flexible section of track (thin rubber membrane), joining the bowl track to the sloping track, could be used to turn the components gradually as they are conveyed.
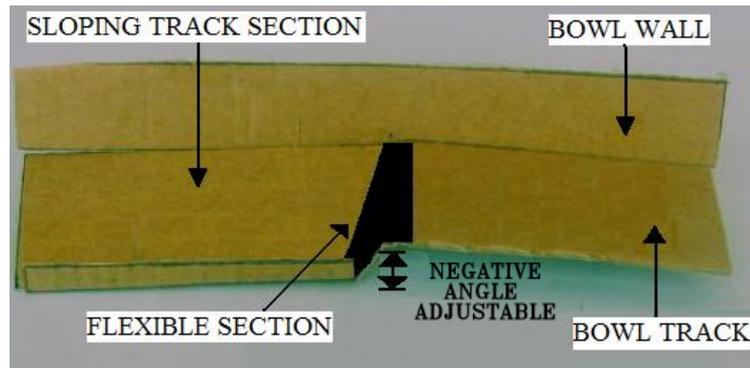
Fig. I-26: The Sloping Track Tool Concept Model

Design Functionality - This tool should function effectively for various disk shaped components. The components will have to negotiate the rubber membrane section as they are conveyed from the bowl track onto the sloping track section. This could cause unsteady transfer motion and possibly result in unintentional reorientation. One solution to this problem might be to use a flexible section of plastic material (vinyl polymer) that has a lower coefficient of friction which should help to promote a smooth conveying action.

Technical Feasibility - The development of a prototype tool would involve the programmability of a section of track through various negative angles. This could be achieved using the standardised stepper motor drive system via a linkage system attached to the sloping track section.

The Operation of the Programmable Sloping Track Tool

A prototype design would consists of a combination of mechanical parts (Fig. I-27). Having demonstrated the concept model, drawings were produced for the design of the prototype tool (Prototype #1).
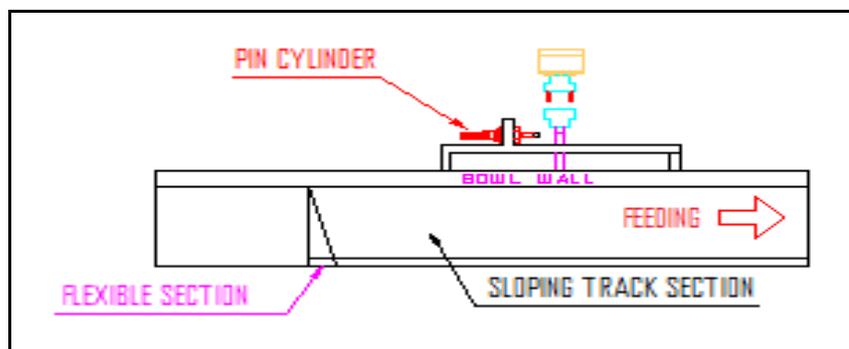
Fig. I-27: Plan View of a Programmable Sloping Track Tool

The objective is to raise and lower the sloping track section of tool incrementally and

independently of the bowl track.   To achieve this objective a mechanical linkage system   attached to the slopping ledge section from beneath is operated via a treaded shaft mechanism that can be driven by a standardised stepper motor drive system.   To lower the sloping track tool into a negative position the stepper motor is rotated anti clockwise moving the linkage mechanism back slowly, guided by the roller and slides. The roller and slide mechanism is used to assist in a smooth action of this mechanical motion.   The sloping track section is now moving backwards and downwards into a lower position (Fig. I-28).
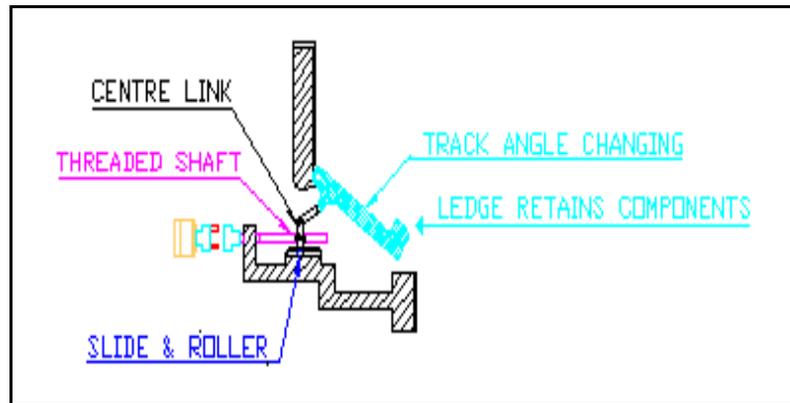
Fig. I-28: Programmable Sloping Track Tool in the Lowered Position

To raise the sloping track section (Fig. I-29) the stepping motor rotation is reversed. When either action has occurred (raising or lowering), the threaded shaft is locked in position using a carefully positioned pin cylinder as the stepper motor drive system is disengaged.   The proposed replaceable and manual adjustable retaining ledge arrangement has not been shown.   Further design work will be necessary to complete this.
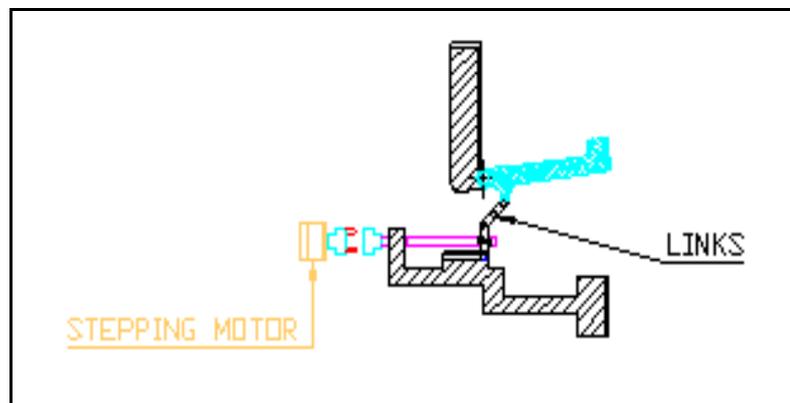
Fig. I-29:   Programmable Sloping Track Tool in the Raised Position
Design Discussion

This design concept should work in practice after some slight modifications e.g. the

linkage mechanism might need to be more rigidly secured. It is also possible that vibrations transmitted to the sloping track through these linkage mechanism may be excessive. A pin cylinder conveniently located to prevent vibrations could be one solution to this problem.

Component Range

The sloping track tool was designed to accommodate various disc shaped components such as washers etc. The tool when fully raised is effectively a normal section of vibratory bowl track. A negative track angle of 90° should be provided to accommodate a wide range of components.

- Component **diameter** is limited as follows:
  - The track width from the bowl wall (0mm) to the edge of the VBF is 24mm, hence a permissible component diameter of 24mm applies.
- Component **height** is limited as follows:
  - Unlimited on height (a practical limit might apply and will depend on the centre of gravity of the components and the height of the sloping track tool ledge).

6 The Scallop Track Tool (Notch Module)

The scallop track tool is the second orientation device to be encountered by the cup-shaped components in the orientation system (Fig. I-30). The tool is classed as a passive orientation device as it rejects components in one of two orientations back into the VBF, in this case assisted by the wiper blade tool.
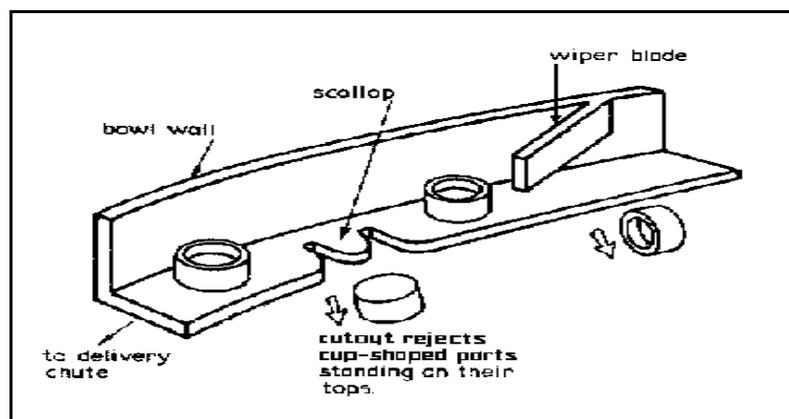
Fig. I-30: Orientation of Cup Shaped Parts in a VBF (Boothroyd, 1981)

The conventional tool consists of a section of track machined out in the shape of a scallop; this uses the difference in shape between the bottom and top of the component to select the required orientation. Undesired orientations in this case are components

standing on their tops (hollowed out section facing downwards).

Design Data to Consider in the Development of a Programmable Scallop Track Tool

Boothroyd, briefly discusses the functions of the scallop track tool but does not provide the necessary design data required for its development. It was initially considered by the author, having researched the functions of the scallop track tool, that the following design data should be considered important in the design of a programmable scallop track tool.   The Radius (**R**) of the scallop machined into the bowl track that effectively rejects components standing on their tops.   The Distance (**D**) between the centre point of the scallop and the bowl wall (Fig. I-31).
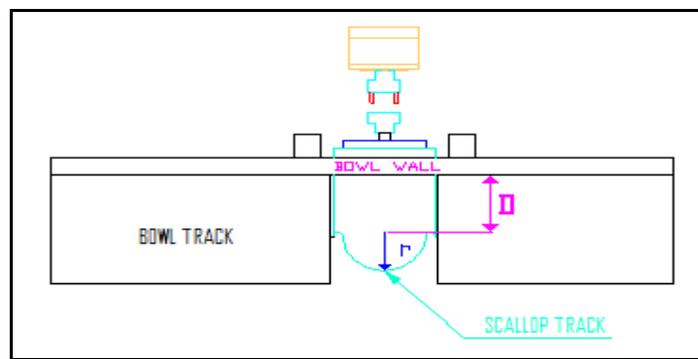
Fig. I-31: Data to Considered in the Design of a Scallop Track Tool

Factors to Consider in the Design of the Programmable Scallop Track Tool

The important factors to consider in the design of the programmable scallop track   tool are as follows:

- It is considered important that the motion of the tool for axial adjustment be fully controlled.
- The magnitude of the device parameters should be determined from the dimensions of the AMTLAB vibratory bowl feeder.
- A programmable scallop could probably consist of replaceable sections of track with various radii in the shape of a scallop, helping to accommodate a wide range of components.
- Axial adjustment should be accomplished using a linear cross roller slide and a carrier section similar to that demonstrated with the narrow track tool (see Section 4.4.3 previously).

The Programmable Scallop Track Tool Concept Model

A design concept was developed that was based again on numerous designs.   This final design was developed with the aid of a specially constructed 3D cardboard model (Fig. I-32) as before.
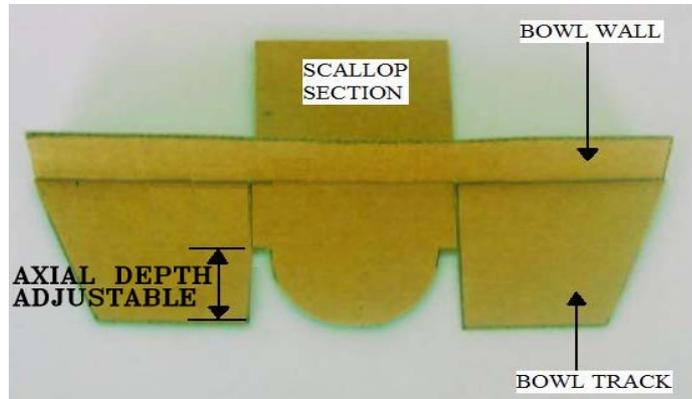
Fig. I-32: The Scallop Track Tool Concept Model

The concept model consists of an axial adjustable track section with replaceable sections of track (Fig. I-33).   When developed the tool will produce various depth configurations for each of the scallop track sections used.
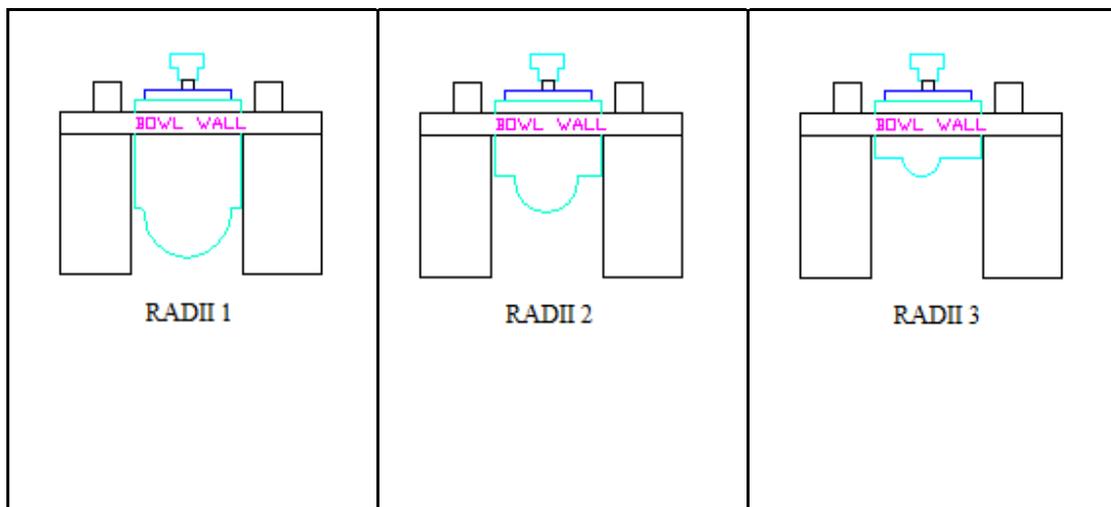

Fig. I-33: Replaceable Scallop Track sections with various Radii

Design Functionality - The components must negotiate a step from the bowl track onto the scallop track section, for selection/orientation and off again back onto the track. The possibility of unsteady transfer motion and unintentional reorientation could occur but as demonstrated before with the narrow track tool this did not happen.

Technical Feasibility -   The development of a programmable scallop track tool would

involve the use of a linear cross roller slide and carrier section to enable track depth adjustment.

Operation of The Programmable Scallop Track Tool

The programmable scallop track tool consist of a replaceable section of track mounted on a carrier that is attached to a linear cross roller slide. The cross roller slide is attached to a treaded shaft.   When the shaft is rotated by the standardised stepper motor drive system the slide moves linearly (Assisted by the bearings) and this will vary the Distance (D) of the scallop track tool accordingly (Fig. I-34).
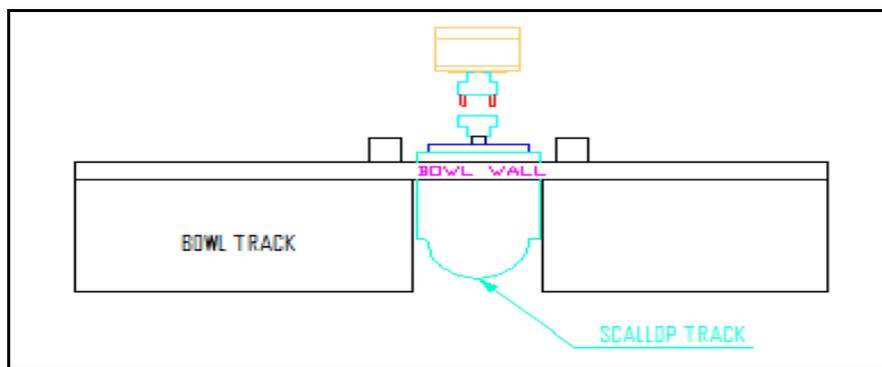
Fig. I-34: Plan View of the Programmable Scallop Track Tool

The carrier performs the function of varying the Distance (D) from the centre of the scallop to the inside edge of the bowl wall. This should help to provide experimental data on the most efficient Distance (D) for various cup shaped components of different dimensions.
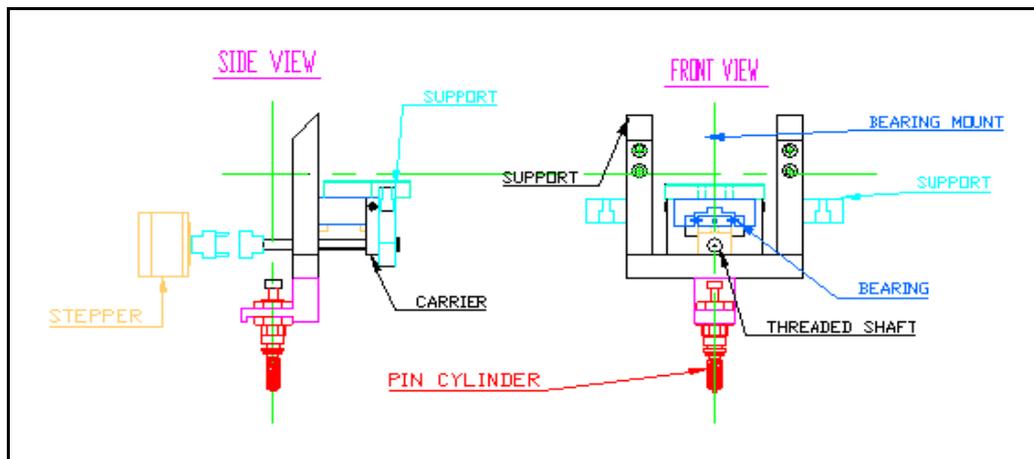
Fig. I-35: Side View and Front View of the Programmable Scallop Track Tool
Figure I-35, shows the components of the assembly. As each new position of the scallop track tool has been obtained the tool will be locked in position by a carefully

positioned pin cylinder. Therefore the vibrations of the VBF should not affect the position of the scallop track section.

Design Discussion

This orientation tool should not be as difficult to manufacture and assemble as some of the tools mentioned previously. The main difference between this tool and the others (except for the manually replaced ridge on the sloping track tool) is that it consist of replaceable scallop track sections for use with components of different radii. This would certainly prove to be a disadvantage as change-over-times (down time) would increase as it would involve manual contact. When developed the tool it should be automated using a stepping motor drive system similar to that demonstrated on the wiper blade tool. It would then be possible to determine the most efficient Distance (D) for each scallop track section used. To enhance tool development and automation the possibility of providing an adjustable scallop track section that accommodated various radii would need to be considered.

Component Range

- Component **height** is limited as follows:

    Unlimited on height (a practical limit might apply and should probably be the height of the distance between the bowl and the track or possibly the tool slide under-clearance).

    A minimum height of say approximately 5mm should apply which would permit accurate selection/orientation of components.

- Component **diameter** is limited as follows:

    The maximum diameter of 24mm applies (i.e. the track width), the internal diameter of the hollowed out cup shaped components determines the diameter of the scallop track section used (a minimum wall thickness of say 1mm should apply to permit accurate selection/orientation).

    A minimum diameter of say 5mm should apply (this limit applies to the practicality of feeding and selecting/orientating small components.

7   The V-Cut-Out Tool

The conventional V-cut-out tool (Fig. I-36) as applied to the orientation of truncated cone-shaped components has a replicable section of track that is machined into a

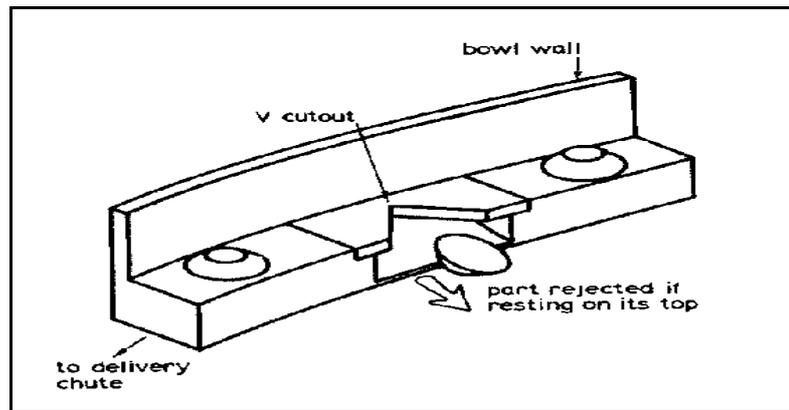V-shaped cut-out (notch) and attached to the bowl at a convenient location.

Fig. I-36: Orienting of Truncated Components (Boothroyd, 1981)

Manually adjustable or replaceable sections of track are employed to accommodate various angles and diameters of components. Undesired orientations in this case are components being fed base upwards. The tool functions as a passive orientation device rejecting components being fed base upwards while accepting components being fed on their bases. The V-shaped cut-out tool is used to reject any component that is travelling on its smallest diameter. The feed rate of components that pass the v-cut-out tool will depend on the number of components that encounter the v-cut-out tool and the proportion of these components that are resting on their smaller diameter.

Design Data to Considered in the Development of a   Programmable V-Cut-Out Tool

In accordance with Boothroyd, the symmetrical orienting device might be described completely by using only two parameters; the half angle of the cut-out (θ) and the distance (**b**) from the apex of the cut-out to the bowl wall (Fig. I-37a). A programmable v-cut-out tool will accommodate both device parameters, with axial and cut-out angle adjustment to permit the selection/rejection of a wide range of components. Since the height of the component has no affect on the performance of the device, the only component (Fig. I-37b) parameters necessary to describe its important characteristics are the radius of the Base (R_d)   and the radius of the Top (R_D).
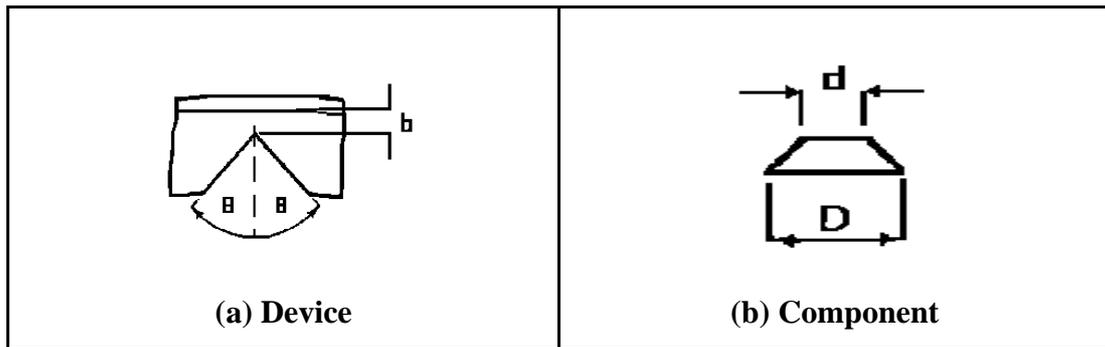
(a) Device	(b) Component

Fig. I-37: Parameters to consider for the V-Cut-Out Tool (Boothroyd, 1981)

Factors to Consider in the Design of the Programmable V-Cut-Out Tool

The other important factors to consider in the design of the programmable v-cut-out tool are as follows:

- It is important that the motion of the tool for both axial or cut-out angle adjustment are intermittently and independently controlled.

- The magnitude of the device parameters should be determined from the dimensions of the AMTLAB vibratory bowl feeder.

- Sequential operation of the Slides A and B (Fig. I-38) act in opposite directions to produce maximum and minimum values for the half Angle θ.

The Programmable V-Cut-Out Tool Concept Model

A design concept was developed based on a number of design sketches. The final design was developed with the aid of a specially constructed 3D cardboard model (Fig. I-38). The purpose of the 3D model was to demonstrate and evaluate the prototype design as a viable solution towards programmability of the conventional tool as before.
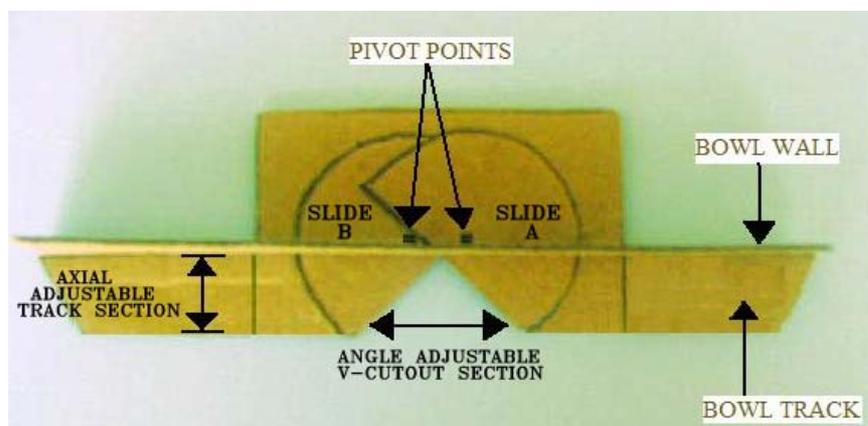
Fig. I-38: The V-Cut-Out Tool Concept Model

The concept model consists of an axial adjustable track section that contain two centrally mounted overlapping wafer-thin slides. The discs form the angle adjustment tracks when open. The slides have straight cross-sections removed that when fully closed are aligned with the edge of the bowl track and parallel to the bowl wall. This means that when the tool is not in use and therefore fully closed it would form part of the bowl track and would not have to be removed from the VBF when not in use.

Design Functionality - The components must negotiate various steps as they pass-by the v-cut-out tool. The first step is between the bowl track and the axial adjustable track. The secondly step is from the axial adjustable track to the angle adjusting slides. The third step is across the overlapping step formed between the angle adjusting slides. These steps may result in unsteady transfer movement or unintentional reorientation.

Technical Feasibility - The development of a programmable v-cut-out tool would involve the use of a linear slide (carrier) to enable track width adjustment and an interlinking gear system to enable slide rotation.

Operation of the Programmable V-Cut-Out Tool

To maximise the parameters for any component the half angle θ will have limits of $\theta = 0^o$ and $\theta = 45^o$. Hence 2θ will give an included working angle of 90° over any distance b = 0 and b = 24mm (.i.e. the track width in this particular case).
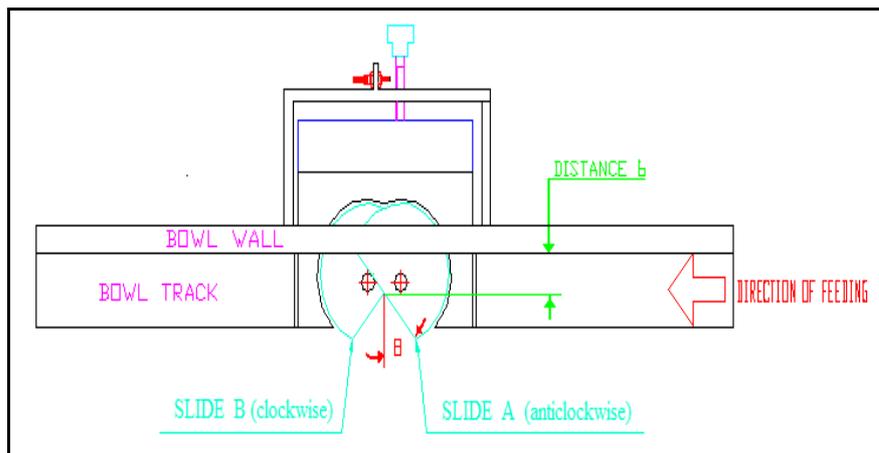

Fig. I-39: Plan View of a Programmable V-Cut-Out Tool

In Fig. I-39 above the two rotational slides, Slide A and Slide B are used to form various angles of θ, resulting in an included angle of $2\theta = 90^o$ when fully open, $2\theta = 0^o$ when fully closed (or when not in use). Both of these slides could be made of wafer-thin stainless steel and coated if required with the same material as the material in

the bowl. Slide A will rotate slightly above Slight B but neither should protrude above the VBF track. Both slides are mounted on a linear axial slide (carrier). This carrier will be used to control the distance (b) from the apex of the v-cut-out section to the bowl wall. The most challenging part to this design is to perform axial and angle configurations of the tool for maximum and minimum values of θ and b, through the operation of a single threaded shaft using the standardised stepper motor drive system (Fig. I-40).
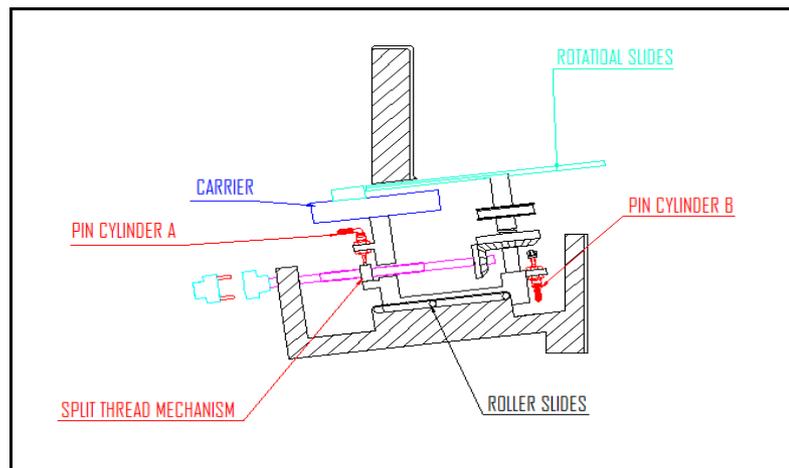

Fig. I-40: Side View of the Programmable V-Cutout Tool

In Fig. I.40 above it can be seen that obtaining the required mechanical motions is not simple. The threaded shaft provides clockwise and anti clockwise rotation of the tool. When the pin Cylinder A, is extended the split thread mechanism disengages the carrier from the threaded shaft. This allows the bevel gears to rotate sequentially moving Slides A and B at the same time in the desired rotation. When the required axial Angle θ is obtained the stepping motor stops rotating and the pin Cylinder A is retracted.

To move the carrier only, pin Cylinder B is extended. This disengages the larger bevel gear from the smaller one (as it is spring mounted) and will provide just enough clearance to disconnect the drive. The entire assembly will now move with the carrier. This is necessitated by the roller slides and grooves. The roller slides will also balance the structure at an included angle of 7°. As soon as the stepper motor stops, the Distance B from the bowl wall has been set. The pin Cylinder B will be retracted, the larger bevel gear (spring return) will return to its normal position (engaged with the smaller bevel gear) and the assembly will be locked in position by pin Cylinder A.

It might be difficult to imagine how both Slides A and B rotate in opposite directions, but it is important that they do and that they maintain a constant angle between them. In Fig. I-41 below it can be seen how the drive pulley, positioned under Slide A and attached to the larger bevel gear drive shaft, can be used to rotate Slide A.
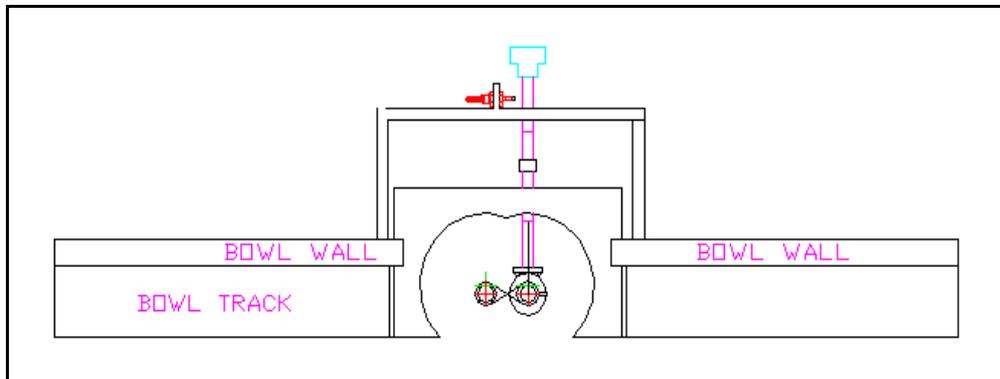

Fig. I-41: Plan View of V-Cutout Tool with Slides Removed

A V belt (Toothed) can be attached to the drive shaft of Slide B. This provides rotation to Slide B. If the V belt is crossed over, both shafts will rotate at the same time but in opposite directions. This means that the half Angle θ can be produced in sequence by each slide and will provide a sufficient working Angle of 2θ during experiments.

Design Discussion

This tool may prove difficult to manufacture due to the small size of the mechanical assembly. Each part including the pin cylinders will be small. However it could be manufactured and assembled and can be fully commissioned prior to attachment on the VBF. The idea of the split thread mechanism will have to be proved as before. If the toothed belt does not work sufficiently two gears could be used that have the same dimensions leaving them with a 1 to 1 gear ratio. These gears will provide clockwise and anticlockwise rotation to the slides as required.

Component Range

It is considered that the AMTLAB v-cut-out tool when fully manufactured and assembled should have a component operating range as follows:

- Component *height* is limited as follows:

    Unlimited on height (a practical limit might apply and should probably be the height of the distance between the bowl and the track or possibly the tool slide under-clearance.

A minimum height of say approximately 5mm is necessary to permit accurate selection/orientation between the bigger and smaller diameter.

- Component *Larger Diameter* is limited as follows:

    The maximum diameter of 24mm applies (i.e. the track width).

    The minimum diameter of say 4mm should apply. This limit applies to the practicality of feeding and selecting/orientating small components.

- Component *smaller diameter* is limited as follows:

    The smaller diameter is expressed as a percentage of the larger diameter, by d/D. The effectiveness of the v-cut-out tool will be compromised the closer the percentage of d/D gets to 100% (.i.e. when d=D). A maximum smaller diameter guideline figure of approximately 75% of the larger diameter is suggested to provide accurate tool effectiveness for a sufficiently wide range of truncated components.