

**User Guide**

**Motor Controls**

Two controls are available to manipulate the operation of the motor driving this device:

1. **Driving gear speed** is controlled by the knob on the rear face of the console. During operation, the drawing speed will also depend on the ratio of the two drawing gears being used: smaller drawing gears will rotate faster. After assembling the desired gear train, use the speed control knob to regulate the speed of the pen as required.
2. **Driving gear rotation** can be controlled using the switch at the rear of the console. This switch has three options: forward, off and reverse. Note that the direction of rotation of the drawing gears will also depend on the number of intermediate gears used in the gear train, and it is possible to have each drawing gear rotating in opposite directions if two gears are in the drive train on one side, and three on the other (see the table of gear trains below for details).

**Drawing Gears**

Each gear can be used as a drawing gear, except for the two largest (95, 102) and the motor gear (16). Drawing gears are held in place by inserting a 4mm axle through the central hole, and then into the drawing gear locator (the single hole on each side towards the front of the console) with two 4mm washers beneath the gear to reduce friction.

One or two drawing gears can be used, with greater complexity possible using two drawing gears simultaneously. If one drawing gear is used, the other arm of the pantograph will need to be pinned through the unused drawing gear locator.

Each drawing gear has one or more 3mm hole positioned at the 3, 5 and 9 o’clock points. The larger gears with more than one 3mm hole have holes located at 5mm intervals closer to the centre. This allows the pantograph arms to be connected in a variety of radii, and attaching the arm closer to the centre will reduce the size of the drawing, without changing the pattern.

Larger gears also have one or more 4mm hole at the 12 o’clock point which allow secondary drawing gears to be attached when the ring gear is deployed (see instructions for this operation later).

**Gear Train Assembly**

To assemble the gear train, begin by deciding which drawing gear you want to use, and fix it in place. Consult the gear train table to find the gears needed for assembling a gear train that will drive the drawing gear in either the forward or reverse direction. The table lists the gears required in order from the motor gear towards the drawing gear.

Assemble the gear train, fixing each gear with a 4mm axle - to find the proper hole, mesh the gear with its fixed neighbour and roll it around the gear until a hole in the console matches the central hole in the gear. As with the drawing gear, place two 3mm washers under each gear to reduce friction and maintain alignment.

Using a single motor to drive the two drawing gears maintains relative speeds that are solely determined by the ratio of the drawing gears, and ensures that patterns resolve when complete.

**Pantograph Assembly**

The pantograph has two types of arms – and extender, and a pen holder, which has a 10mm hole towards one end. The extender is attached to the drawing gear by the hole closest to an end.

The pantograph arms are then attached to the drawing gear using an inverted 3mm screw. This is best done before the drawing gear is located on the console, by inserting the screw through the chosen 3mm hole from underneath. Add a nut to hold the screw in place, and then slip the pantograph over the screw, with a 3mm lock nut above the pantograph arm to hold it in place during operation.

When the two extender arms are attached, choose a crossing point that allows free movement beyond the front of the console (larger gears can be crossed closer to the console). Cross the extenders over so a 3mm screw can be inserted through both gears from underneath, with a washer between them, and fix the screw in place using a 3mm lock nut. Make sure the nut is not so tight that the arms can scissor freely during operation.

With the pen hole outermost, attach the ends of each pen holder arm to the extenders, using a 3mm screw , washer and lock nut as before. Take care to maintain vertical alignment, by keeping one arm on top throughout the assembly. Draw the free ends of the pen holder arms together, and insert the pen to hold them in place.

Prepare the pen by rolling an o-ring on from the bottom. Adjust the height of the arms by sliding the o-ring along the pen until everything looks level, and add another o-ring from the top to secure in place.

Attaching the pantograph arms in different places will affect the size of the drawing: if the pen holder arms are longer than the extender arms, the drawing will be proportionally enlarged, and if the extender arms are longer, the drawing will be reduced.

The pen holder arms could also be crossed and connected unevenly, using another 3mm screw and lock nut which will skew the drawing, and give two possible locations for the pen (which is mounted on a single arm, again using the o-rings). By changing the arm holding the pen, multiple patterns can be superimposed.

**Using the Ring Gear**

The ring gear is mounted on top of the wooden supports by placing a 4mm axle through the holes. No washer is required under this gear because it does not rotate. To use this gear, mount a secondary drawing gear on top of the primary through one of the 4mm hole at the 12 o’clock direction with an axle and supporting washers as before. Only smaller gears can be used for this. Ensure that the small gear meshes with the ring gear during operation.

Now attach the pantograph arms to the secondary gear as before. When operating, the pantograph now executes a series of additional twirls as the small gear is driven around the inside of the ring gear, adding further complexity to the drawing.

**Exploring the Mathematics**

Patterns will show symmetry depending on the ratios of the drawing gears. Simple ratios (1:2, for example) will give simple patterns with two axes of symmetry. Complex ratios and those with prime factors will show more complex symmetry.

Having drawing gears rotating in opposite directions will also change the patterns in systematic ways.

These patterns only depend on the ratios of the two final gears in the entre train, and different gear train combinations should have no effect.

The patterns which emerge are a visual representation of the underlying mathematics, and recognizing, exploring and predicting these outcomes offers a way to engage the user with increasingly complex mathematical relationships.

**Gear Train Table**

Other combiinations may be possible. All have 16 motor gear.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Drawing gear** | **Forward** |  | **Reverse** |  |
|  | train |  | Secondary Drive | train |
| 20 | 64, 120 |  | 20/4 | 45, 120 |
| 23 | 45, 120 |  | 20/2 | 32, 120 |
| 25 | 32 120 |  | 20/3 | 25, 120 |
| 32 | 64, 120 |  | 20/4 | 45, 120 |
|  |  |  |  |  |
| 35 | 56, 120 |  | 20/4 | 25, 120 |
| 40 | 32, 120 |  | 20/2 | 32, 120 |
| 45 | 32, 120 |  | 20/2 | 64, 95 |
|  |  |  |  |  |
| 48 | 64, 95 |  | 20/2 | 64, 95 |
| 50 | 32, 95 |  | 20/5 | 20, 95 |
| 56 | 20, 102 |  | 20/1 (32) | 32, 102 (48, 95) |
|  |  |  |  |  |
| 63 | 95, 77 |  | 20/4 | 75, 77 |
| 64 | 32, 102 |  | 20/2 | 45, 91 |
| 75 | 20, 91 |  | 20/3 | 25, 77 |
|  |  |  |  |  |
| 77 | 45, 95 |  | 20/4 | 35, 95 |
| 80 | 32, 64 |  | 20/2 | 45, 95 |
| 91 | 45, 48 |  | 20/2 | 35, 95 |
|  |  |  |  |  |
| 95 | 32, 91 |  | 20/2 | 32, 50 |
| 102 | 45, 75 |  | 20/3 | 25, 50 |