

Workshop 2 — Motor Mounting and LEGO Gearboxes

Wednesday, January 4, and Thursday, January 5, 2005

1 Items to Bring

- All of your LEGOs

2 Reading

Sections 4.1 and 6.4.1–6.5.4 in course notes

3 Motors

- **Speed.** The motor has 100 discrete speeds. However, due to mechanical and slight physical differences between each motor, the motors do not spin at equal speeds when they run in either direction. When separate motors run separate gear trains, they will each have slightly different speeds, thus your robot will not necessarily go straight when it should. As a result other techniques such as shaft encoding may be needed to correct the imperfections of the motor.
- **Soldering.** Two wires are needed to drive your motors. Since the motors can spin both ways, there's no reliable way to tell forward from backward while wiring. Section 4.3 in the course notes shows you what kind of connector you will need to connect to the Handy Board's motor ports. Solder each lead to the motor with utmost care: The metal tabs on the motor can be very fragile, and the plastic around the tabs can melt when near a soldering iron, rendering the tabs brittle. We suggest using a small amount of hot glue to the soldered connection, once you're certain the motor works. We also recommend soldering the motor before LEGOizing it.
- **Gear on the motor.** Section 4.4 of the course notes includes instructions for mounting a LEGO gear on the motor shaft. There are many ways to mount the 8-tooth gear, so if you feel like getting creative, go ahead but be careful (motors cost \$1, and the supply is not infinite). A common alternate method is to carefully squeeze the 8-tooth gear such that it fits snugly around the gear already on the slimmer. A little super-glue will fully bind the two gears together, without the need for shrink wrap. Be careful not to glue the motor shaft in place.
- **“LEGOizing” Your Motors**
 - **Motor jig.** See Section 4.4 to find how to construct the jig (the jig is reproduced in Figure 1. This LEGO gadget is useful for ensuring that the gears align. If your motor's gear is even a little bit off, you will notice it in both the performance of your robot and the sound that emanates from your robot. Reducing as much friction between LEGOs will lead to faster locomotion.
 - **Custom modifications.** Instead of using the jig, you can alter the LEGO on your chassis to accommodate the motor, and directly put the motor onto the chassis. A disadvantage of this approach is that you lose modularity—should you decide on a new design, you cannot just take the motor out and stick it somewhere else on your robot.

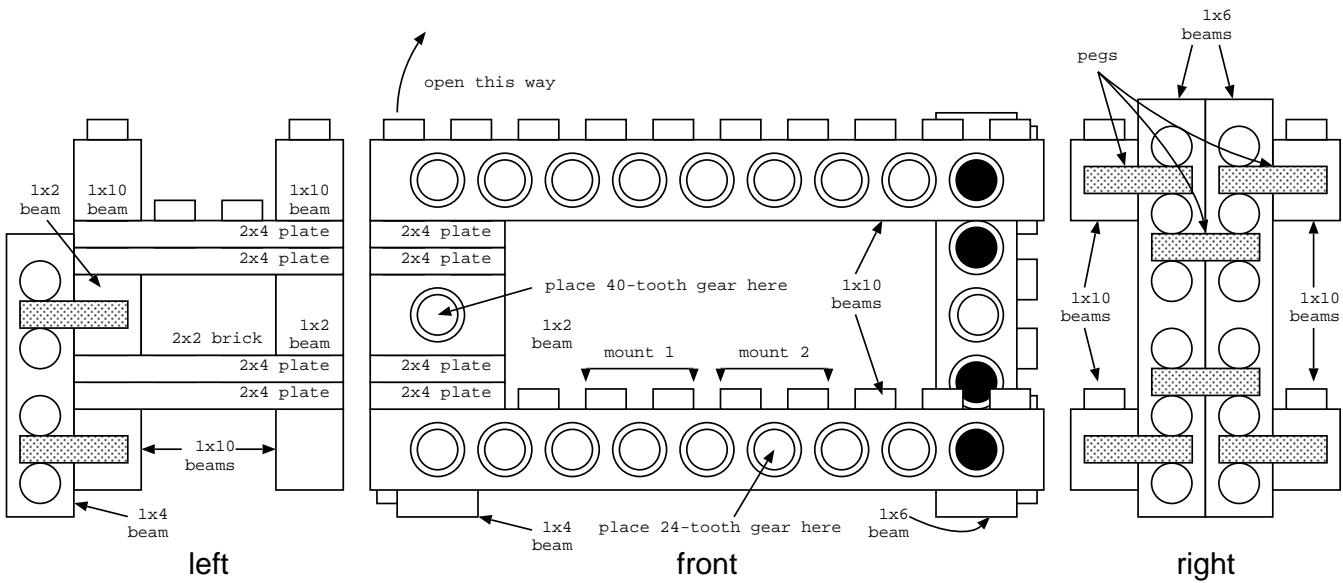


Figure 1: Motor Jig

4 LEGO Gearboxes

These provide the motion

- **Calculating reduction.** The easiest way to calculate gear reduction is to first explain how everything is connected from the gear on the wheel axle to the last meshing gear. For example, with the gear train given in Figure 2 we can say: “There is a 40-tooth gear which meshes with an 8-tooth gear that is on the same axle as a 24-tooth gear, which meshes with an 8-tooth gear that is on the same axle as a 24-tooth gear, which meshes with an 8-tooth gear.” (The last 24-tooth gear is not meshing with anything, and so therefore does not affect the gear ratio. Although the motor would be meshing with that particular 24-tooth gear, when concerning gear ratios we only want to compare the first and last LEGO axles of the gear train.) Given this description, replace every “which meshes with” with \div and every “on the same axle as” with \times . Thus, the gear reduction is $40 \div 8 \times 24 \div 8 \times 24 \div 8 = 5 \times 3 \times 3 = 45 : 1$.

We recommend having a gear reduction between 27:1 and 90:1. The motors run at a very high RPM (revolutions per minute) when not driving a load (gear train or robot). Assuming the motor spins around 4500 RPM at top speed while in your robot, a gear ratio of 45:1 means the drive wheel will spin 100 times in 60 seconds, the duration of the contest. The circumference of the large LEGO wheel is roughly 9 inches, meaning your robot can travel 75 feet during the contest, or approximately 9 table lengths.

Likewise, a gear ratio of 90:1 using the large wheels will net you about 4.5 table lengths of travel during the competition. In our experience, robots rarely travel this far, but if your strategy is to do laps around the table, it’s something to keep in mind. This is also why it is crucial that you test your robot under full load—with the Handy Board and the Hawker battery pack physically weighing down the robot.

- **Gear sizes.** You have several different sizes of gear teeth: 8, 12, 16, 24, and 40. The 16-tooth gears do not mesh as easily as the 8-, 24-, and 40-tooth gears do. The 12-tooth gears are in the differential pack, but are very weak, and are not recommended for use in the gear box. The 24-tooth gears are crown gears.
- **Backdriving.** How do you know if you’ve built a good gear train? An easy way to check is to temporarily remove the motor, and spin the drive wheel with your hand (motion from the drive wheel transmitted to the

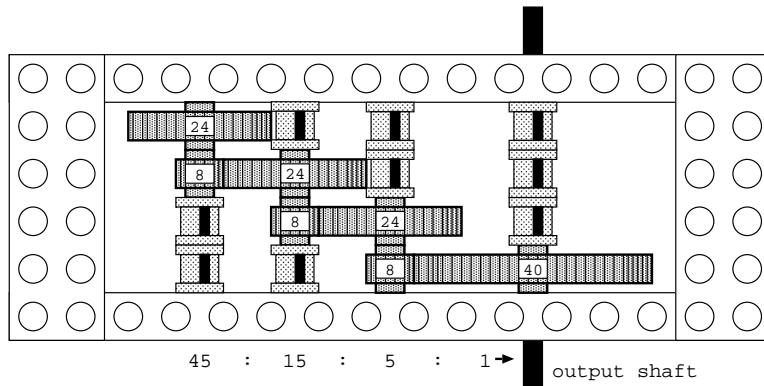


Figure 2: LEGO gearbox

motor gear is called backdriving). If the gears in the gear train keep spinning for a while, and if the motion is fairly quiet, you've built an efficient gear train. If the gears stop spinning almost immediately, or if you hear rattling or grinding, take a look at your LEGO structure to make sure it doesn't bend or flex, and that all gears have free motion.

- **Optimizing space.** Of course, your robot will have to do many tasks, other than simply driving. Making small and compact drive mechanisms gives you greater freedom to make the rest of your robot functional as well. Some tricks of the trade include using the 8-tooth to 40-tooth meshing to quickly increase the gear ratio. Notice that the demo robots in lab have a 40-tooth mounted inside the wheel hub, meshing with an 8-tooth gear. Also, worm gears can give you gear reductions of 40:1, or even 60:1 (worm gear to turntable) in a very small space. A team from two years ago built a 1024:1 gearbox, roughly the size of a can of soup.
- **Drive mechanisms.** See Section 6.5 in the course notes. Described therein are three basic types of drive mechanism commonly used in 6.270. It's possible to make wildly exotic, and extremely useful drives by combining and augmenting these basic types.

5 Some Tips

- **Bushing orientation.** The full bush has two sides. One has a cross pattern, and the other side is a circle. The cross side has a small surface area, and your gearbox will experience less friction due to the bushing.
- **Don't forget about bracing.** Remember to brace well, and to brace either perpendicularly or according to Pythagoras' theorem. Many robots that were incorrectly braced left trails of "LEGO dust" along the ground due to grinding gears. You do not want to (unknowingly) add unnecessary shear forces to your gearbox due to improper bracing.
- **Baseplate.** Remember that you can make modifications to your baseplate in order to accommodate your motors and servos.
- **Tires.** Your robot will face a lot of weight, and the rubber tires will often have a difficult time moving, particularly when trying to begin to move. Turning tires in place can also twist the tires, eventually wearing the tread down or warping the tire until it is useless. This often happens because there is nothing but air between the hub and the tire, and as a result, the tire has a lot of free room to twist. Several solutions exist to fix this problem—either add electrical tape to the tire to reduce the coefficient of friction, or stuff the tire with LEGO (particularly the chain) to strengthen the tire.

- **Placement of tires.** Remember that friction slows down your robot. Your robot will undoubtedly be heavy, and will put much strain on your gearboxes. The axles will not be straight, and if your wheels are placed too far outside the chassis, they will also play a part in bending the axles. Try to encircle your robot's tires with LEGO to keep the axles straight.
- **Weight placement.** The best place to put your Handy Board and batteries is directly over your gear train and wheel. Putting them to the side will add a force that could strain your rotating axles. Therefore, consider other configurations, like putting a separate battery over each gear train, rather than adding a pack of batteries on top of your robot.
- **Why have one when you can have...** There is no reason why you need to have only one motor on a gearbox. Putting another motor on the gearbox can add additional torque, which will lead to a faster robot. And if you place two motors in each gearbox such that one motor runs clockwise while the other runs counter-clockwise, you can ensure that the gearbox would run at more equal speeds in either direction than if the motors attached were all going the same direction.
- **Treads.** Don't forget you can use rubber bands to strengthen your treads.
- **Eschew from the crown gear.** Unless absolutely necessary, try to keep the gears in your gearbox all parallel. Using crown gears weakens your gearbox because they are structurally weaker.
- **Curse that 16-tooth gear.** The 16-tooth is very difficult to mesh with your other gears. Avoid it.
- **And the worm gear.** Though the worm gear will give you a large reduction (just putting the worm gear against an 8-tooth already gives you a 8:1 ratio), structurally the worm gear is weak and will not bode well in a gearbox. It is useful for doing more specific, and less load-bearing tasks such as running mechanisms for arms.

6 Activity

With your kit build a gearbox with a ratio between 45:1 and 90:1. Attach a wheel on the final axle, and check to see that it backdrives effectively.

Once you have done this, try and see if you can reduce the space the gearbox takes. Then build another gearbox that is a mirror image of the first one. Put them together and you're halfway there to finishing Assignment 2.