Chapter 5

Mechanics of Robots

On successful completion of this course, students will be able to:

- Explain principle of some mechanics devices for robots.
- Describe some type of gears.
- Describe about arm geometries.
- Describe about kinematics of robot.

Introduction

In intelligent robotics, a manipulator is a device used to manipulate materials without direct contact. For example, using robotic arms, we can develop robotically-assisted surgery. It is an arm-like mechanism that consists of a series of segments, usually sliding or jointed, which grasp and move objects with a number of degrees of freedom. Modern robotics needs excellent gears. A good understanding of how gears affect parameters such as torque and velocity are very important. Gears work on the principle of mechanical advantage. This means that by using different gear diameters, you can exchange between rotational (or translation) velocity and torque.

Introduction of Gears

With gears, you will exchange the high velocity with a better torque. This exchange happens with a very simple equation that you can calculate:

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Torque_Old * Velocity_Old = Torque_New * Velocity_New
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Torque_Old and Velocity_Old can be found simply by looking up the datasheet of your motor. Then what you need to do is put a desired torque or velocity on the right hand side of the equation. So for example, suppose your motor outputs 3 lb-in torque at 2000rps according to the datasheet, but you only want 300rps. This is what your equation will look like:

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3 lb-in * 2000rps = Torque_New * 300rps
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Then you can then determine that your new torque will be 20 lb-in. The gearing ratio is the value at which you change your velocity and torque. Again, it has a very simple equation. The gearing ratio is just a fraction which you multiple your velocity and torque by. Suppose your gearing ratio is 3/1. This would mean you would multiple your torque by 3 and your velocity by the inverse or 1/3 [5].

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Example: Torque_Old = 10 lb-in, Velocity_Old = 100rps

Gearing ratio = 2/3
Torque * 2/3 = 6.7 lb-in
Velocity * 3/2 = 150rps
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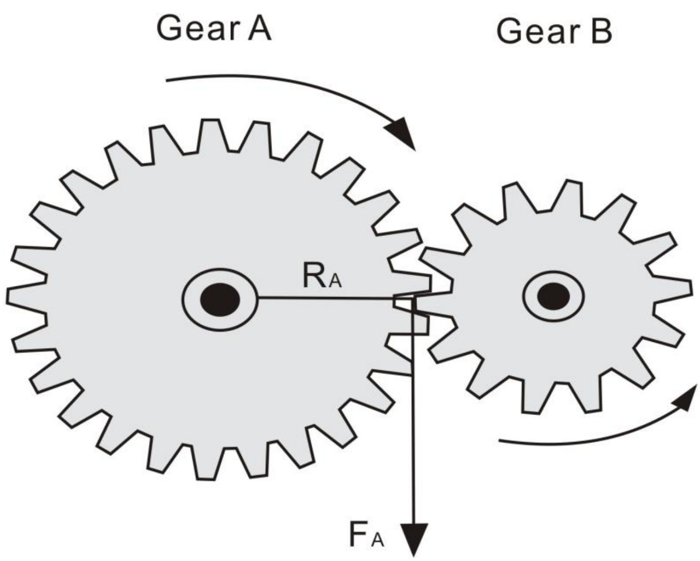


Figure 5.1 *Torque that generates to rotates gear B equal to F_A x R_A.*

If you wanted a simple gearing ratio of say 2 to 1, you would use two gears, one being twice as big as the other. It isn't really the size as much as the diameter ratio of the two gears. If the diameter of one gear is 3 times bigger than the other gear, you would get a 3/1 (or 1/3) gearing ratio. You can easily figure out the ratio by hand measuring the diameter of the gears you are using. For a much more accurate way to calculate the gearing ratio, calculate the ratio of teeth on the gears. If one gear has 28 teeth and the other has 13, you would have a (28/13=2.15 or 13/28=.46) 2.15 or .46 gearing ratio. I will go into this later, but this is why worm gears have such high gearing ratios. In a worm gear setup, one gear always has a single tooth, while the other has many - a guaranteed huge ratio. Counting teeth will always give you the most exact ratio.

Unfortunately, by using gears, you lower your input to output power efficiency. This is due to obvious things such as friction, misalignment of pressure angles, lubrication, gear backlash (spacing between meshed gear teeth between two gears) and angular momentum, etc. For example, suppose you use two spur gears, you would typically expect efficiency to be around 90%. To calculate, multiply that number by your Velocity_New and Torque_New to get your true output velocity and torque [3][4].

Gearing ratio = 2/3

Torque * 2/3 = 6.7 lb-in

Velocity * 3/2 = 150rps

true torque = 6.7 * .9 = 6 lb-in

true velocity = 150 * .9 = 135rps

Types of Gears

Some types of gears have high efficiencies, or high gearing ratios, or work at different angles, for example. Often manufacturers will give you expected efficiencies in the datasheets for their gears. Remember, wear and lubrication will also dramatically affect gear efficiencies. Spur gears are the most commonly used gears due to their simplicity and the fact that they have the *highest possible efficiency* of all gear types. Not recommend for very high loads as gear teeth can break more easily.

Figure 5.2 *Spur Gears, with ~ 90 % efficiency.*

Two gears with a chain can be considered as three separate gears. Since there is an odd number, the rotation direction is the same. They operate basically like spur gears, but due to increased contact area there is increased friction (hence lower efficiency). Lubrication is highly recommended.

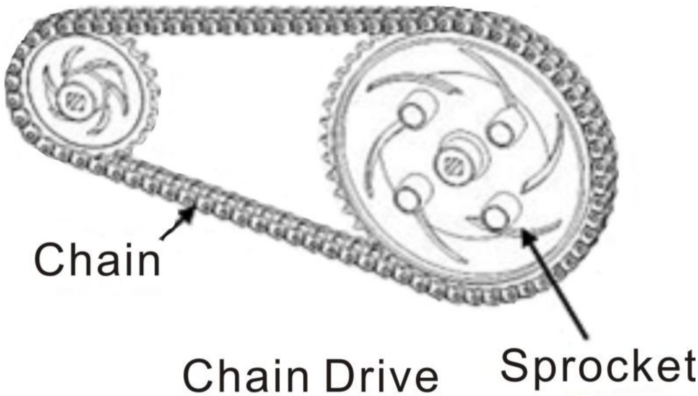


Figure 5.3 *Sprocket Gears With Chains, with ~80% efficiency.*

Worm gears have a very high gearing ratio. To mathematically calculate, consider the worm gear as a single tooth. Another advantage to the worm gear is that it is not back-drivable. What this means is only your motor can rotate the main gear, so things like gravity or counter forces will not cause any rotation. This is good say if you have a robot arm holding something heavy, and you don't want to waste power on holding torque.

Figure 5.4 *Worm Gears with ~70% efficiency.*

Rack and Pinion Gears

Rack and Pinion is the type of gearing found in steering systems. This gearing is great if you want to convert rotational motion into translational. Mathematically, use radius = 1 for the straight 'gear'.

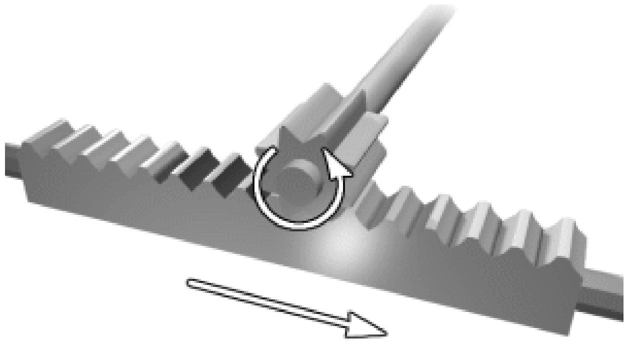
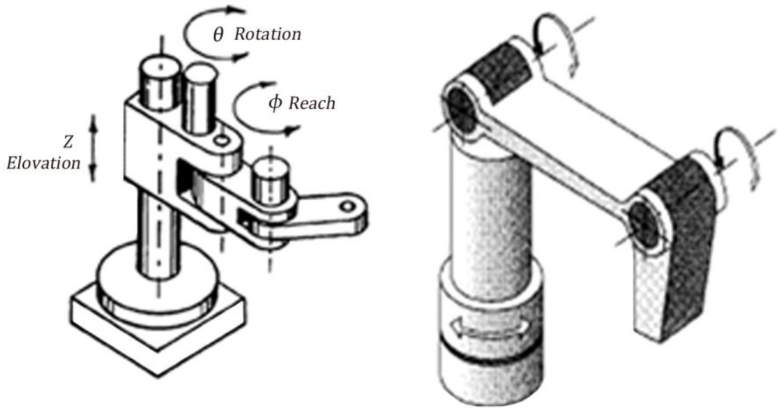


Figure 5.5 *Rack and Pinion, with ~90% efficiency.*

Arm Geometries

Generally, there are five configurations robots used in industry, namely: Cartesian Robot, Robot Cylindrical, Spherical Robots, Articulated Robots (consist of revolute joint RRR), SCARA (Selectively Compliant Assembly Robot Arm). They are named for the shape of the volume that the manipulator can reach and orient the gripper into any position—the work envelope. They all have their uses, but as will become apparent, some are better for use on robots than others. Some use all sliding motions, some use only pivoting joints, some use both. Pivoting joints are usually more robust than sliding joints but, with careful design, sliding or extending can be used effectively for some types of tasks [1].

The Denavit-Hartenberg (DH) Convention is the accepted method of drawing robot arms in FBD's. There are only two motions a joint could make: translate and rotate. There are only three axes this could happen on: x, y, and z (out of plane). Below I will show a few robot arms, and then draw The Robot Arm Free Body Diagram (FBD). A cartesian coordinate robot (also called linear robot) is an industrial robot whose three principal axes of control are linear (i.e. they move in a straight line rather than rotate) and are at right angles to each other. Cartesian coordinate robots with the horizontal member supported at both ends are sometimes called Gantry robots. [2]



(a) (b)

Figure 5.6 *Example of SCARA Configuration (a) and articulated (b).*

Example of Manipulator for industry is KUKA KR 5 arc rounds off the range of KUKA robots at the lower end. Its payload of 5 kg makes it outstandingly well-suited to standard arc welding tasks. With its attractive price and compact dimensions, it is the ideal choice for your application too. Whether mounted on the floor or inverted overhead, the KR 5 arc always performs its tasks reliably.

Figure 5.7 *KUKA Manipulator for Industry suitable for welding, soldering and painting [6].*

Kinematics of Robot

Kinematics studies the motion of bodies without consideration of the forces or moments that cause the motion. Robot kinematics refers the analytical study of the motion of a robot manipulator. Formulating the suitable kinematics models for a robot mechanism is very crucial for analyzing the behavior of industrial manipulators. Robot kinematics applies geometry to the study of the movement of multi-degree of freedom kinematic chains that form the structure of robotic systems. Robot kinematics studies the relationship between the dimensions and connectivity of kinematic chains and the position, velocity and acceleration of each of the links in the robotic system, in order to plan and control movement and to compute actuator forces and torques.

The robot kinematics can be divided into forward kinematics and inverse kinematics. Forward kinematics problem is straightforward and there is no complexity deriving the equations. Hence, there is always a forward kinematics solution of a manipulator. Inverse kinematics is a much more difficult problem than forward kinematics. The solution of the inverse kinematics problem is computationally expensive and generally takes a very long time in the real time control of manipulators. In forward kinematics, given the length of each link and the angle of each joint, we can find the position of any point (it's x,y,z coordinates). And for inverse kinematics, given the length of each link and the position of some point on the robot, we can find the angles of each joint needed to obtain that position.

References

[1] E. Sandin (2003), Paul, Robot Mechanism and Mechanical Devices Illustrated, Mc-Graw Hill.

[2] C. Dorf, Richard (2000), The Electrical Engineering Handbook, CRC Press LLC.

[3] http://www.societyofrobots.com/mechanics_gears.shtml.

[4] B., Owen (2007), Robot Builder's Cookbook, Elsevier Ltd.

[5] http://www.fi.edu/time/Journey/Time/Escapements/geartypes.htm.

[6] KUKA-robotics.com.