From the six simple machines to complex kinematic linkages, every engineer needs to be familiar with the basics of machinery movement. If your knowledge base requires refreshment, this fact-filled, illustrated eBook — Simple and Compound Machines — presents a colorful and enlightening reminder of how machines do their work. The following topics are covered: Kinematic linkages, transducers, simple machines, rotary-to-linear conversion, and drive mechanism basics.
Simple and Compound Machines

Six simple machines: No matter how complex, all machines are based on one or more simple machines that change the direction or magnitude of an applied force. Simple machines include the lever, wheel and axle, pulley, inclined plane, wedge, and screw.

Kinematic linkages: Connecting linkages at joints form mechanisms, the building blocks of higher systems and machines. Kinematics, first coined by Andre Marie Ampere from the Greek word cinematique for motion, is the study of this motion without regard to forces.

The ultimate map of transducers: Here we map the family of motion devices that convert energy to and from four common forms: Fluidic, mechanical translational, mechanical rotational, and electrical.

Drive mechanisms: There’s more than one way to drive a load. What’s best depends on what you’re trying to do.

Rotary to linear motion: Ballscrews, threaded shafts, and belts are among the most commonly used elements to convert rotary motion to linear motion. Each fits specific application needs for speed, accuracy, life, and cost — and affects a system’s frequency response.

Kickstart and other new videos

Have you seen the newest products launched by AutomationDirect? Now you can watch short videos with product descriptions, features and tips. Our new “KICKSTART” video program can be found on our Learn site and on our YouTube channel. Check out these short two-minute videos on products such as our new compact air cylinders, coiled air hoses, compact fuse switches and more.

Visit http://learn.automationdirect.com and look for the Kickstart tab along the top. Or, go to www.youtube.com/automationdirect, where you can subscribe to our YouTube channel and leave comments on each video.

Other videos released recently include a four-part tutorial series where product manager Jeff Payne shows you how to use the many features of the Productivity3000 PAC programming software. Watch these under the Software tab on the Learn site.

VEX Robotics World Championships

AutomationDirect was pleased to sponsor the recent VEX Robotics World Championships at the ESPN Wide World of Sports Complex (within Disney World) near Orlando, Florida April 14-16. Over 500 teams comprised of 3,500 high school, middle school, and collegiate students came to together to celebrate their accomplishments and compete with (and against) the best of the best. These were the top robotics teams from over 200 VEX tournaments that took place around the world from May 2010 to March 2011.

Eleven teams from our local school system (Forsyth County, GA) qualified to attend, and one of those teams (from North Forsyth High) made it to the semifinal round! Congratulations to all the teams who made it to Orlando.

After a series of intense back-to-back matches and elimination rounds, the High School Champion alliance emerged with teams comprised of Massachusetts’ Green Egg Robotics Club, Washington’s W.A.S.A.B.I. 2 and Ontario, Canada’s Simbotsics teams.

The Middle School Champion represented an alliance of China teams from Sichuan Chengdu Longjiang Road Primary School and the Shanghai Luwan Teenagers Activity Center.

The College Championship title went to Massey University from New Zealand. In addition, one team from each of the three divisions was presented with an Excellence Award, the highest honor in the VEX Robotics Competition, given to the team with the most well-rounded VEX Robotics Program.

Middle School, High School and College Excellence Award winners included, the VEXMEN: NightCrawler team from Downingtown Area Robotics in Downingtown, Pennsylvania, the Cheesy Poofs from Bellarmine College Prep in San Jose, California, and Massey University in New Zealand.
Six simple machines

Machines consist of elements, such as gears and bearings, that work together to transmit force and produce work. No matter how complex, all machines are based on one or more simple machines that change the direction or magnitude of an applied force. Simple machines include the lever, wheel and axle, pulley, inclined plane, wedge, and screw.

Wheel and axle
This device consists of a wheel attached to an axle where torque applied to the wheel winds a rope or chain onto the axle. It’s a lever in principle, but it can move a load farther than a lever can. In a winch, the rope that carries a load is wrapped around the axle. A light force applied to a crank handle on the side of the wheel creates torque about the axle centerline (the fulcrum) to lift a heavy load.

Lever
A lever consists of a bar pivoted on a support or fulcrum, and used to increase an applied force. In a first class lever, such as a crowbar, the fulcrum is between the load and applied force. In a second class lever, such as a wheelbarrow, the load lies between fulcrum and force. In a third class lever, the force is between load and fulcrum.

Pulley
Resembling a wheel and axle, a pulley has a rope or belt that passes over it to lift a load. A fixed pulley attached to a support changes the direction of a force. This makes it easier to lift a load by pulling down on a rope and using body weight as an assist. With a movable pulley, a rope supported at one end wraps around the pulley and is pulled up at the other. Pulling upward lifts the load (and pulley) with only half the effort -- the support gives the added effort. In another form, pulleys drive a belt or chain.

Inclined plane
The inclined plane is a flat object positioned at a slope or incline to aid in lifting. Consider the difficulty in trying to lift a 200-lb load up into the rear of a truck. But placing a 10-ft plank from the truck to the ground lets you slide the load up into the truck easily. The inclined plane principle is used in conveyors.

Wedge
The wedge is an adaptation of the inclined plane. It is thick at one end and tapered to a thin edge at the other for insertion in a narrow crevice. It can raise a heavy load over a short distance, tighten an assembly, or split a log when driven by a hammer. The smaller the angle of the thin end, the less force is required to raise a load. Shaft locking devices use the wedge principle.

Screw
The screw is an inclined plane cut in a spiral around a cylinder. A jackscrew, used to raise large structures, combines the usefulness of both the screw and lever. The lever turns the screw, and only a small effort is needed to raise a heavy load. Screws also provide linear motion in ball screws and screw conveyors.
Fourbars are so prevalent because of their simple elegance; they contain the fewest parts while still returning a degree of freedom. Capable of many types of motion, possible forms include the sliders, cranks, and rockers.

Connecting linkages at joints form mechanisms, the building blocks of higher systems and machines. The mobility of any mechanism can be quantified by its degrees of freedom, which is defined as the number of inputs needed to fully control output motion.

Kinematics

Let freedom ring

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Fourbar family

Fourbars are so prevalent because of their simple elegance; they contain the fewest parts while still returning a degree of freedom. Capable of many types of motion, possible forms include the sliders, cranks, and rockers.

Spring-loaded structure

Structure

Roller mechanism

Crank

Cylinder joint

Planar joint

Spherical joint

Joints with two degrees of freedom are also known as half-joints.

Exchanging actuators for linkage constraints is common practice when building robots with multiple degrees of freedom. The resulting motion is more complex but comes at a cost.

The Kutzbach modification determines a system’s degrees of freedom as Greubler’s equation does, but makes working with grounded links and half-joints easier:

\[ M = 3(L-1) - 2F - H \]

where \( M \) is the degrees of freedom, \( L \) is the number of links, \( F \) is the number of full links, and \( H \) is the number of half links.

The Grashof condition determines whether a fourbar contains a link capable of full revolution or only partial rotation:

\[ S + L \leq X + Y \]

where \( S \) is the shortest link’s length, \( L \) is the longest link’s length, and \( X \) and \( Y \) are the remaining links’ lengths. When the condition is met with both sides equal, full linkage revolution will be possible, but at two positions the output will be indeterminate.

Freedom Fighters

Greubler

Kutzbach

Grashof

Kinematics, first coined by Andre Marie Ampere from the Greek word cinematiq for motion, is the study of this motion without regard to forces. Because every input requires an actuator and must be coordinated with other inputs, keeping system complexity and degrees of freedom as low as possible helps keep cost low too.
Mechanical rotational

Brakes and clutches

Couplings

Bearings and bushings

Laminations help here.

Overly ductile shafts can deflect and fail. Operation at critical speed induces resonance and allows centrifugal force to exaggerate eccentricity, possibly to failure. When rates beyond critical speed are required, quality moving through a hub. Stepped geometries to accommodate gears and pulses (and displacements) are local. Any on (and displacement) can bring bearings and potential bringing trouble spots.

Bearings and bushings

Bearings, or journal bearings, are components, while elastomeric static gaskets fill space between two clamped other components, springs also decrease or in a housing. Under constant loading, both can also as spacers to compensate for radial and axial dimensional variation and to isolate rotational vibrations. Application considerations: Rings and springs increase precision and predictability of load-deflection curves. By taking advantage of clearance in bearings and other components, springs also decrease wear and increase life. Other uses include oil in and on all alike.

Gear couplings couple shafts to transfer torque and angular velocity while allowing for some misalignment. Application considerations: Couplings can be used to tweak system dynamics. Metallics are torsionally stiff and impact high natural frequencies in systems, while metallic macro-insert couplings have natural frequencies below operating points to absorb resonance excitation. Wedge varies from about 0.05 with bellows, up to 0.25 with beem couplings.

Bearings and bushings

Bearings, or journal bearings, are sleeves that transmit load by sliding on an oil film. In anti-friction bearings, rolling, load-carrying elements carry axial and radial loads on a shaft. Application considerations: Though negligible compared to that of bushings, roller bearing starting friction is old wise running friction.

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The following illustrations are a reminder that there’s more than one way to drive a load. You can use gears, belts, cams, screws, or even a rack-and-pinion. What’s best depends on what you’re trying to do. If you want to achieve, say, a complex cyclic motion in a nasty environment, you might consider using a cam. If simplicity is the goal and you have a relatively low-inertia load, direct drive may be the answer to your needs.
Ball screws, threaded shafts, and belts are among the most commonly used elements to convert rotary motion to linear motion. Each fits specific application needs for speed, accuracy, life, and cost. Also, each affects a system’s frequency response through backlash or torsional and axial stiffness.

**Operation:** A toothed belt attached to a carriage passes around a pulley in each end of an actuator. A carriage, joined to the belt and supported by a linear bearing system, is pulled back and forth along the length of travel. **Application considerations:** Offers highest operating speeds, but low repeatability and positioning accuracy. Converts more than 90% of motor energy to thrust. However, tensile strength of transport belt limits thrust capability, and it backdrives easily.

**Operation:** In a simple reciprocating device, the input and output shafts are in line with each other. Rotating the input crank causes the second link to oscillate, resulting in the output shaft moving back and forth in linear motion. **Operation:** Two or more rings, suspended through ball bearings, are held at non-ninety degree angles on a smooth shaft. The shaft rotates the bearings in the rings, resulting in the rings moving linearly along the shaft. **Application considerations:** Low friction and noise. Some models backdrive easily, but a third ring can be used to control this. Very high speed, can double that of ballscrew systems. Converts about 90% of energy into motion.

**Operation:** One or more circuits of recirculating balls roll between the ballnut and threaded screw. **Application considerations:** Converts more than 90% of motor torque to thrust, allowing use of small gears, clutches, and drive motors. High positioning accuracy and repeatability, with duty cycle to 100%. Maximum operating speed depends on screw’s critical speed and ball recirculation speed. There’s a tendency to backdrive, so you may need a brake or holding device. Plus, they can be noisy and they have a low tolerance for shock loads.
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Cycloid gear mechanism

Operation: Adjustable ring gear meshes with worm gear for infinitely variable stroke length. Rotating inside the ring gear is a planet gear that is half the ring gear's diameter. One end of the connecting rod is pinned to the planet and moves back and forth as the gear rotates in the ring.

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