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ACTUATORS AND DRIVES FOR AN INDUSTRIAL ROBOT: A REVIEW

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ABSTRACT - A robot joint mechanism consists of at least four major components: the joint axis structure, an actuator, transmission, and state sensor (usually for position feedback, but velocity and force sensors are also common). For low-performance manipulators that accelerate the payload at less than a peak of 0.5 g, system inertia is not as important as gravity forces and torques. This means the actuators can be placed near the joints, and their suspended weight compensated using counterbalancing masses, springs, or gas pressure. In high-performance robots where peak payload accelerations reach 3–10 g or more, minimizing system inertia is important. The actuators are placed near the first joint axis of a serial link manipulator to minimize its inertial contribution, and drive links, belts or cables or gear transmissions are used to drive the joints.

ACTUATORS

Actuators supply the motive power for robots. Most robot actuators are commercially available components, which are adapted or modified, as necessary, for a specific robot application. The three commonly used actuators are hydraulic, pneumatic, and electromagnetic.

Hydraulic Actuators

Hydraulic actuators, chosen as power sources for the earliest industrial robots offer very large force capability and high power-to-weight ratios. In a hydraulic system the power is provided mechanically from an electric motor or engine driven high-pressure fluid pump. Actuators are most commonly linear cylinders, rotary vane actuators, and hydraulic motors.

Actuator control is through a solenoid valve (on/off control) or a servo valve (proportional control), which is driven electrically from a low-power electronic control circuit. The hydraulic power supply is bulky and the cost of the proportional, fast-response servo valves are high. Leaks and maintenance issues have limited the use and application of hydraulically powered robots.

Pneumatic Actuators

Pneumatic actuators are primarily found in simple manipulators. Typically they provide uncontrolled motion between mechanical limit stops. These actuators provide good performance in point-to-point motion. They are simple to control and are low in cost. Although a few small actuators may be run with typical factory air supplies, extensive use of pneumatic-actuated robots requires the purchase and installation of a costly dedicated compressed-air source. Pneumatic actuators have low energy efficiency. Proportional closed-loop, servo-controlled pneumatic manipulators have been developed and successfully applied, principally in applications where safety, environmental, and application conditions discourage electric drives. An example is an early version of the DeLaval International AB Tumba, Sweden VMS (Voluntary Milking System) cow-milking robot, which used pneumatic actuators and electro-pneumatic proportional valve joint controls in a farm, milking stall, environment.

Electromagnetic Actuators

The most common types of actuators in robots today are electromagnetic actuators.

Stepper Motors

Small, simple robots, such as benchtop adhesive dispensing robots, frequently use stepper or pulse motors of the permanent magnet (PM) hybrid type or sometimes the variable reluctance (VR) type. These robots use open-loop position and velocity control. They are relatively low in cost and interface easily to electronic drive circuits. Microstep control can produce 10 000 or more discrete ors and robot motions have a significant settling time, which can be damped either mechanically or through the application of control algorithms. Power-to-weight ratios are lower for stepper motors than for other types of electric motors. Stepper motors operated with closed loop control function similarly to direct-current (DC) or alternating-current (AC) servomotors.

Permanent-Magnet DC Motor

The permanent-magnet, direct-current, brush-commutated motor is widely available and comes in many different types and configurations. The lowest-cost permanent-magnet motors use ceramic (ferrite) magnets. Robot toys and hobby robots often use this type of motor. Neodymium (NEO) magnet motors have the highest energy-product magnets, and in general produce the most torque and power for their size. Ironless rotor motors, often used in small robots, typically have copper wire conductors molded into epoxy or composite cup or disk rotor structures. The advantages of these motors include low inductance, low friction, and no cogging torque. Disk armature motors have several advantages. They have short overall lengths, and because their rotors have many commutation segments, they produce a smooth output with low torque ripple. A disadvantage of ironless armature motors is that they have a low thermal capacity due to low mass and limited thermal paths to their case. As a result, when driven at high power levels they have rigid duty-cycle limitations or require forced-air cooling.

Brushless Motors

Brushless motors, also called AC servomotors or brushless DC motors, are widely used in industrial robots. They substitute magnetic or optical sensors and electronic switching circuitry for the graphite brushes and copper bar commutator, thus eliminating the friction, sparking, and wear of commutating parts. Brushless motors generally have good performance at low cost because of the decreased complexity of the motor. However, the controllers for these motors are more complex and expensive than brush-type motor controllers. The brush- less motor's passive multipole neodymium magnet rotor and wire-wound iron stator provide good heat dissipation and excellent reliability. Linear brushless motors function like unrolled rotary motors.

Other Actuators

A wide variety of other types of actuators have been applied to robots. A sampling of these include, thermal, shape-memory alloy (SMA), bimetallic, chemical, piezoelectric, magnetostrictive, electroactive polymer (EPAM), bladder, and micro-electromechanical system (MEMS) actuators. Most of these actuators have been applied to research and special application robots rather than volume production industrial robots. An example of a piezoelectric actuator powered robot is the six-axis PI piezo hexapod with sub-nanometer resolution.

DRIVES

The purpose of a transmission or drive mechanism is to transfer mechanical power from a source to a load. The design and selection of a robot drive mechanism requires consideration of motion, load, and power requirements and the placement of the actuator with respect to the joint. The primary considerations in transmission design are stiffness, efficiency, and cost. Backlash and windup impact drive stiffness especially in robot applications where motion is constantly reversing and loading is highly variable. High transmission stiffness and low or no backlash results in increased friction losses.

Most robot transmission elements have good efficiencies when they are operating at or near their rated power levels but not necessarily when lightly loaded. Larger than necessary drives adds weight, inertia and friction loss to the system. Under designed drives have lower stiffness, can wear rapidly in continuous or in high duty cycle operation or fail due to accidental overloads. Joint actuation in robots is generally performed by drive mechanisms which interface the actuator (mechanical work source) to the robot links through the joints in an energy-efficient manner. A variety of drive mechanisms are incorporated in practical robots. The transmission ratio of the drive mechanism sets the torque, speed, and inertia relationship of the actuator to the link. Proper placement, sizing, and design of the drive mechanisms set the stiffness, mass, and overall operational performance of the robot. Most modern robots incorporate efficient, overload damage resistant, back-driveable drives.

Direct Drives

The direct drive is kinematically the simplest drive mechanism. In the case of pneumatic or hydraulic actuated robots, the actuator is directly connected between the links. Electric direct-drive robots employ high torque, low-speed motors directly interfaced to the links. The complete elimination of free play and smooth torque transmission are features of a direct drive. However, there is often a poor dynamic (inertia ratio) match of the actuator to the link requiring a larger, less energy efficient, actuator.

Band Drives

A variant of direct drive is band drive. A thin alloy steel or titanium band is fixed between the actuator shaft and the driven link to produce limited rotary or linear motion. Drive ratios in the order of up to 10:1 (10 actuator revolutions for 1 revolution of the joint) can be obtained. Actuator mass is also moved away from the joint – usually toward the base, to reduce robot inertia and gravity loading. It is a smoother and generally stiffer drive than a cable or belt drive.

Belt Drives

Synchronous (toothed) belts are often employed in drive mechanisms of smaller robots and some axes of larger robots. These function much the same as band drives, but have the ability to drive continuously. Multiple stages (two or three) of belts are occasionally used to produce large drive ratios (up to 100 : 1). Tension is controlled with idlers or center adjustment. The elasticity and mass of long belts can cause drive instability and thus increased robot settling time.

Gear Drives

Spur or helical gear drives provide reliable, sealed, low-maintenance power transmission in robots. They are used in robot wrists where multiple axes intersect and compact drive arrangements are required. Large diameter, turntable, gears are used in the base joints of larger robots to handle high torques with high stiffness. Gears are often used in stages and often with long drive shafts, enabling large physical separation between actuator and driven joint.

Planetary gear drives are often integrated into compact gear motors. Minimizing backlash (free play) in a joint gear drive requires careful design, high-precision and rigid support to produce a drive mechanism which does not sacrifice stiffness, efficiency and accuracy for low backlash. Backlash in robots is controlled by a number of methods including selective assembly, gear center adjustment, and proprietary anti-backlash designs.

Worm Gear Drives

Worm gear drives are occasionally used in low-speed robot manipulator applications. They feature right angle and offset drive capability, high ratios, simplicity, good stiffness and load capacity. They also have poor efficiency which makes them non-back-driveable at high ratios. This causes the joints to hold their position when unpowered but also makes them prone to damage by attempts to manually reposition the robot.

Rack-and-Pinion Drives

These traditional components are useful for long motions where the guideways are straight or even curved. Stiffness is determined by the gear/rack interface and independent of length of travel. Backlash can be difficult to control as rack-to-pinion center tolerances must be held over the entire length of travel. Dual pinion drives are sometimes employed to deal with backlash by providing active preload. Forces are generally lower than with screws due to lower ratios. Small-diameter (low teeth count) pinions have poor contact ratios, resulting in vibration. Sliding involute tooth contact requires lubrication to minimize wear.

Other Drive Components

Splined shafts, kinematic linkages (four-bar, slider crank mechanisms, etc.) chains, cables, flex couplings, clutches, brakes, and limit stops are some examples of other mechanical components used in robot drive mechanisms. The Yaskawa Robot World assembly and process automation robots are magnetically suspended, translate on air a planar (two-DOF) bearing, and are powered by a direct electromagnetic drive planar motor with no internal moving parts.

CONCLUSION

The mechanical design of a robot is an iterative process involving engineering, technical, and applicationspecific considerations evaluations, and choices. The final design should reflect consideration of detailed task requirements rather than simply broad specifications. Proper identification and understanding of these requirements is a key to achieving the design goals. Design and choice of specific components involves tradeoffs. A purely static, rigid-body approach to manipulator design is often used, but is not always sufficient. Mechanical system stiffness, natural frequencies, control system compatibility, and intended robot applications and installation requirements must be considered.

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