Designing Fluid Power Systems for Material Handling Applications

Advanced material handling applications can go beyond simply transporting objects on a conveyor belt. In some cases, these applications may involve complex sequences of motion control to position, hold, transport, and steer materials through one or more production processes. The motion control application becomes even more challenging when it involves handling large, heavy items such as logs or metal parts. Fluid power is often used for these types of applications.

Fluid power for material handling applications

If the motion involves lifting and holding heavy objects, applying pressure, or squeezing an object with a controllable force, then fluid power excels. The hydraulic cylinder simply needs to be “locked” to maintain even pressure, while an electric motor, which must continue to exert force, may overheat and fail.

Fluid power also has other advantages in these types of applications. For example, a single energy source of fluid pressure and available flow – such as a compressor or pump – can power many fluid power devices, including a mix of rotary and linear motion devices. The power source can be located away from the motion device, saving weight and space at the point of motion. Fluid power actuators are typically smaller and can cost less than electric motors with the same power.

In addition, because an accumulator (pressure reservoir) is typically used to store energy in a fluid power application, smoothing out pressure transients as the system operates, the pump or compressor can typically be sized to provide a little more than the average pressure and flow required. By comparison, electric motors that are used in material transport systems must typically be sized to handle maximum loads.

Motion requirements for “gripping” applications

Using fluid power and sophisticated motion control, a complex material handling application can include positioning and holding a heavy object in place and conveying it through production processes. Conceptually the operation is straightforward, but a key challenge is designing pressure controls to hold the object firmly without bending or breaking it – especially under potentially powerful counteracting production forces such as cutting or placing components – at high speeds and on the fly.

The system may also require motion controllers that can integrate and control both rotary and linear hydraulic actuators, depending on the required length of the hydraulic cylinder, weight of the object to be moved, and the production process through which the object is being moved.

As described, this material handling application may require multiple types of motion control to be implemented simultaneously and in sequence using a motion profile. As the material moves through the system, the motion controllers may shift on-the-fly from position control to pressure control to velocity control, and each shift must occur smoothly in order to avoid material or machine damage.

Designing the motion control system

In this example of a material handling application, a series of heavy objects to be processed will be scanned and analyzed by a computer, then loaded onto a conveyor and positioned based on computer or operator inputs. This example uses two axes, one at each end of a large object, that move into position at each end of the object. As the two axes come into contact, data about the object is communicated to the motion controller to allow pressure to be released smoothly so that neither the object nor the machine is damaged. An application could coordinate multiple axes, with the motion of one or more axes “geared” to the motion of another, and use a combination of position and pressure controls to engage or “grip” the object. Gearing and gripping (see sidebar) can be used to benefit many material handling applications that need to hold and move objects without damaging them. Once engaged, the object will be moved through the production process by controlling the velocity of the multiple axes moving in tandem, while maintaining position and pressure controls to keep the object from slipping out of place.

The transitions between position, pressure, and velocity control may be coordinated by a programmable logic controller (PLC) or by sequential programming of the motion controller. Data such as size and position of the object, production process details, and motion controller status data will help determine the correct time and position to transition the motion controller from position control (with pressure over-ride), to “geared” control (with pressure over-ride), and velocity control (without pressure over-ride).

Employing the correct control algorithms is critical. For example, controlling the transition between holding position, to applying pressure, to moving while applying pressure involves predicting the motion of one or more of the axes. With data on the size and position of the object (from a PLC or other input), the motion controller can begin to decrease hydraulic pressure in one axis before the second axis is engaged to “grip” the object. This minimizes the pressure spike and reduces hydraulic shock, avoiding damage to the object and lengthening the life of the machine. The incorporation of predictive factors in the motion control algorithm is called feedforward and is very important in achieving the smoothest material transfers.

Without the ability to incorporate predictive factors in the control algorithm, the conventional proportional, integral and derivative (P, I, D) feedback loop must do all the work. Since PID control is responsive only, designed to generate control inputs that eliminate the error between actual and target conditions, a time lag can occur as the error is reduced to zero. During this lag period, material handling errors due to pressure overshoot or undershoot can occur and the object being processed might be damaged or moved out of correct alignment. Ideally, the control system should be set up so that most of the work is done by the feedforward term, with PID inputs being used only to tweak the position or pressure for optimal values.

Motion control guidelines

There are a number of specific motion control issues to consider in designing this type of material handling system. The following guidelines address issues such as avoiding material and machine damage, reducing machine complexity and cost, and anticipating the need to add processes to the application in the future.

1. Employ predictive terms in the control algorithms to do most of the work. If the predictive control output is close to optimal, then the PID portion of the algorithm does less work. Gearing is an example of a motion operation that is entirely predictive.
2. Incorporate pressure control along with position control. Use pressure limits to allow you to grab objects with enough force to hold them without breaking them. Pressure control is the secret to gripping.
3. Ensure that the system is self-adjusting for conditions on the line. Temperature changes will affect viscosity of hydraulic fluid, which can cause the cylinders to overshoot or undershoot and lead to material or system damage. Use a motion controller that can adjust to fluid viscosity changes as they occur.
4. Design the system for flexibility. Material handling applications often require combinations of rotary, linear, and pressure controls. Using motion controllers that can

handle multiple loops allows the designer to reduce the number of hydraulic valves, which dramatically reduces system complexity and cost.

5. Design for expandability. Take advantage of standard networking and fieldbus protocols that make expanding the system a matter of simply adding a network drop for additional motion controllers.

Application example

How these functions can be implemented can be illustrated by an example from the forest products machinery industry. In this example, coordination between multiple motion axes is required to keep both ends of a log clamped as it is cut into boards, while position and pressure control must be deftly managed to make sure that the log is clamped with sufficient force to hold it without damaging it.

Figure 1. End-Dogger Diagram

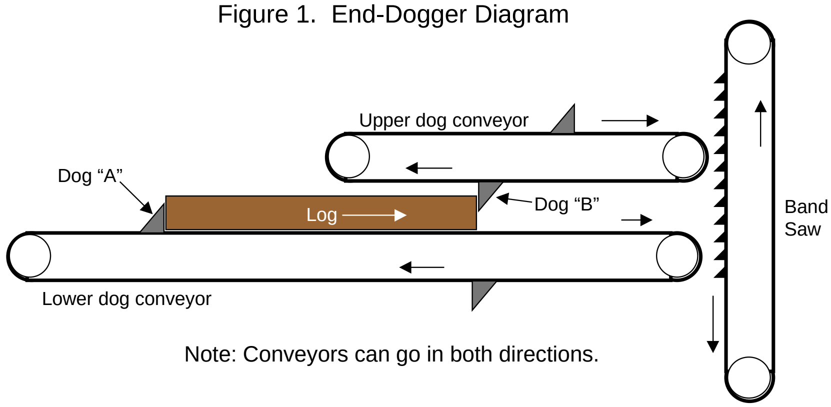
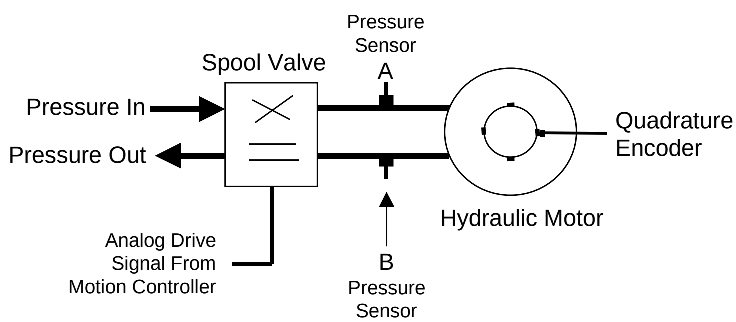


Figure 1 shows a simplified schematic design of an “end-dogger” control scheme developed by Ken Sells and Chuck Reiser of Maxi Mill, Inc. for Boise Cascade. An end-dogger is a material transport system that carries logs through a series of chipping heads and band saws in a sawmill. “Dogs” are the stops that come into direct contact with the log on each end to grip and move the log toward the saws and chippers.

In this application, logs are first loaded onto turning rolls with 4 axes of position control. The logs are laser scanned, and an optimizing computer calculates offset and skew, positioning the log to be cut for the best board yield and assigning a gripping pressure threshold based on the diameter of the log. The log is then loaded onto the conveyor from the side, and the lower conveyor is moved so that dog A pushes the log into contact with dog B on the upper conveyor. Once the dogs are engaged, they move the log through the chip heads and saw, then disengage and release the board. In this case, there are five distinct segments of speed control to cut each log: velocity to engage the back dog, velocity to push the log into the upper dog, velocity to enter the chip heads/saw, velocity in the saw, and exit velocity. A motion profile controls the full process.

The top and bottom conveyors are operated to move dogs A and B to the "home" position ready to receive the log. The conveyors are driven by hydraulic motors, and position is controlled using quadrature inputs from sensors mounted on the conveyor drive axes (see Figure 2). The top dog's pressure setpoint is set to a low value to "receive" the log.

Figure 2. Transducer Connections to Hydraulic Motor



The log is loaded onto the conveyor from the side, and the lower conveyor is moved so that dog A pushes the log into contact with dog B. Pressure transducers are mounted in the hydraulic lines going to and from both hydraulic motors (see Figure 2), so the system knows that the log has come into contact with dog B when dog B begins to move and pressure rises in the line between the valve for dog B and the motor.

Once the pressure measured at the hydraulic motor for the upper dog conveyor exceeds a set threshold, the pressure ramps up to the gripping setpoint value as the control loop controlling the top conveyor motor tries to hold the position of dog B, while the lower conveyor continues to push the log to the right. This creates a position error that will create the gripping pressure.

When the target pressure on the log is reached, based on information from the optimizing computer, the appropriate amount of grip on the log has been reached to hold it steady without damaging it. The log has been engaged, or “dogged.” At this point, the control scheme changes to one that is position controlled (while still monitoring and controlling the maximum gripping pressure), and the top conveyor begins to move in a one-to-one ratio with the bottom conveyor. With this lock-step motion in process, the upper dog conveyor is “geared” to the operation of the lower conveyor. Due to the position error created when the log first engages the top dog and the 1:1 gearing ratio, the gripping pressure is maintained even if the bottom dog stops and reverses drive direction.

The dogs carry the log through the chipping heads and band saws, maintaining constant pressure to ensure smooth motion even against the forces of the cutting heads. Once the log is cut, the system changes the top dog out of gearing mode into velocity mode, sets the pressure high, and accelerates the top dog away from the log. The bottom dog pushes the log out, the position error is cleared from the motion controller, and the top dog goes around and back to the home position.

Motion control concepts

Beyond control of linear or rotary motion, there are a variety of motion control concepts that allow machine designers to take full advantage of the benefits of fluid power.

Gearing is the inter-relating of two or more motion axes in a coordinated manner, such that the motion of one axis depends on the motion of the other. Gearing can be as simple as moving two axes in lock step (1:1 ratio), such as in a simple conveyor application, or as complex as moving one axis at a variable rate compared to another, as in a tensioning or pouring application.

Gripping is common in material handling applications, where an item must typically be gripped between two or more motion axes and moved through a process. The item must be gripped tightly enough that it is not moved out of position during the process, but not so tightly that it is damaged. This can be accomplished by using pressure limiting while gearing the motion of one axis to the motion of another.

Splines define non-linear motion that is a function of position inputs. Based on time or position inputs, which may come from the operator or that the designer programs into the system, the motion controller calculates the smoothly varying motion of an axis.

Camming occurs when the motion of an axis is a variable time function of the motion of another axis, such as in applications where an axis moves in to remove parts from a moving conveyor and moves them to another process.

Synchronizing takes place when multiple axes need to be at a target point at exactly the same time. In many material handling applications, especially those moving large objects, there may be two control axes, one at each end of the object, which must be perfectly synchronized to hold the item in place and to reduce machine wear and tear.

Superimposed moves occur when one axis follows another axis at a predetermined time and for a predetermined time or distance, for instance, to initiate a production process within a motion application that occurs at a given time or place on the conveyor.