Dual Loop Position Feedback for Backlash Compensation

When there is a gear reducer between motor and the load or tool, then there is backlash in the the motion transmission mechanism in a motion control system. It is virtually impossible to have a motion transmission mechanism without some backlash. For example, every gear reducer have some backlash. Timing belts have backlash type effect and loss of motion when motion direction changes, though the backlash amount gets smaller with tension on the belt. Ball-screws have backlash, and lead-screws have more backlash compared to ball-screws (Fig. A-13).

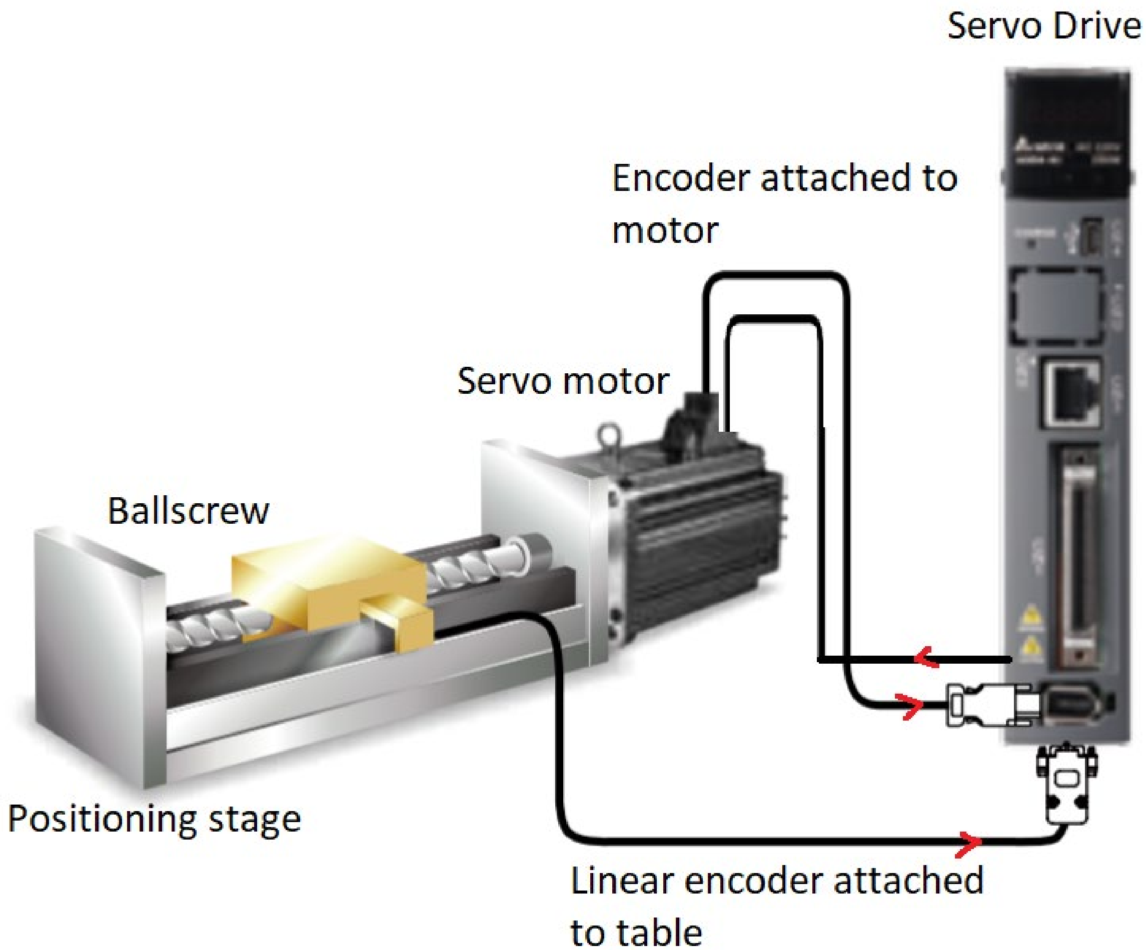
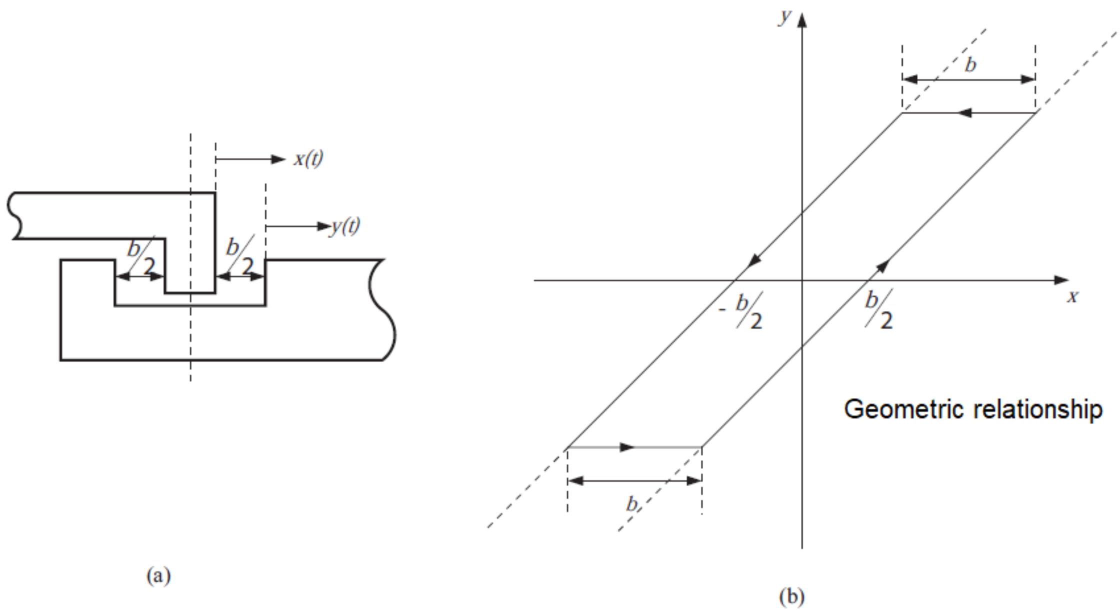


Fig. B-1: Dual position feedback in servo motion control for backlash compensation

Backlash is a geometric space between two contacting teeth (Fig. A-14). So, when motion changes direction, the motion by the amount of backlash distance is lost. There are two common sources of backlash in servo motion control systems:

1. Gear reducer: backlash in the gears. No gear reducer can be made with zero backlash. There are also backlash equivalent effect with timing belts due to its flexibility and the effect of that during change of direction of motion.
2. Motor shaft-flexible coupling: if any two shafts, often motor shaft and flexible coupling, are connected to each other in such a way that when motion direction changes, there can be a small slip between them, then that is effectively backlash. Backlash is likely to occur on **keyway or set-screw** type coupling method between two shafts. It is much better to couple (connect) two shaft via **clamping method, plus with taper lock bushings.**



Backlash phenomenon in motion control systems

There are two ways to deal with backlash (Fig. A-13):

1. Select (design) a motion transmission mechanism such that the backlash is 2 to 5 times less than the positioning accuracy needed. For instance, consider a motor, a gear reducer of ratio 1:1, and output rotary load. Let us assume we need output angular positioning accuracy of 1/10 degrees. If the angular backlash in the gear is 1/20 or even 1/50 th of a degree, we are not concerned about this positioning error due to change in motion direction or load torque. Similarly, if we had a rotary-to-translational motion conversion mechanism, i.e. ball-screw. If we wanted a positioning accuracy of 10 micrometer, the maximum backlash in the lead screw should be at least as small as ½ to 1/5 th of that: 10/2 micrometer to 10/5 micrometer.
2. If backlash is larger than that, i..e 2/10 degree or 2/10 micrometer in above cases, then when motion changes direction or gear contract/ball-screw contact point changes due to load torque/force, there would be 2/10 degree (or 2/10 micrometer) positioning error that motor

based position sensors would not detect and that positioning error is larger than the desired positioning accuracy. The only solution in this case is to use **load-coupled position sensor**. In other words, measure the actual position of the load, “see the positioning error due to backlash” and let the closed loop position control system handle the correction. In very large backlash cases and highly dynamic motion control (i.e. very high repeatation rate of motion involving change of direction of motion), we may need to use two position feedback per motion axis: one motor coupled and one load coupled position sensor.

Such systems are referred as “dual position feedback loops”. In this case, a commonly used servo control algorith logic is that we use motor-coupled sensor for velocity control loop to keep the system stable, and load-coupled sensor to control the position loop accurately. There are other servo algorithms that aims to accomplish even better performace. If motor-coupled sensor feedback position sensor is not used, the closed loop system can potentially be unstable, depending on the relative size of backlash and application motion bandwidth involvng motion direction change. Notice that, due to backlash, motor-load motion has discontinuity when ever motion changes direction. During the backlash period, motor moves, but the load is practically disconnected from it until the backlash distance is travelled and gear-contact is made again. In other words, during backlash motion, the load is not controllable. If the backlash is large and high bandwidth repeatative motion is needed involving motion direction change, dual position feedback is needed. In other cases, using just load-coupled sensor would be sufficient to correct for the backlash error without making the closed loop system unstable.

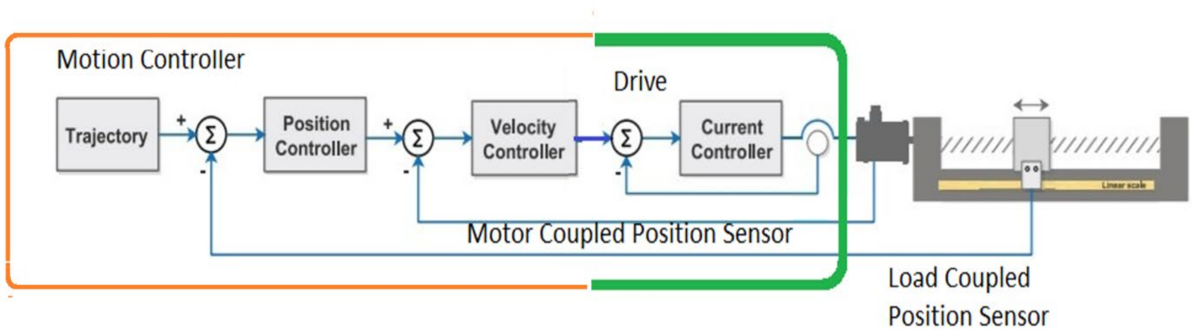


Fig. B-3: Dual position feedback servo control algorithm implementation: an example.

Another effect of backlash is destabilizing (or “buzzing”) effect on the servo loop if the motor inertia and reflelected load inertia ratio is high, i.e. 1:10 or larger (i.e. 1:100). As the motor-effective load inertia match increases to larger numbers, the stability of closed loop servo control and “buzzing” sound around a final stationery position becomes very much a function of the backlash magnitude. For example, a Jm:Jl ratio of 1:50 can be stable and no buzzing if it is directly coupled and virtually there is no backlash in the shaft connections. The same system can become unstable if there is backlash develops to a “large” enough value. How “large” of a backlash causes instability or unacceptable buzzing is application dependent. It is important to note that during backlash two shafts (motor shaft and load shaft) are disconnected. When backlash distance is travelled, they re-connect. This is a rather discontinuous dynamic switching. The larger the backlash is and the larger the load inertia to motor inertia is, the more significant the servo stability problem will become.

Dual (two) position sensors per axis are used in high precision positioning applications where the error caused due to mechanical drive train’s backlash is too large compared to the desired positioning accuracy. The actual implementation of the dual feedback sensor based servo control algorithm can be done either at the servo drive or at the motion controller. Increasingly, current state of art servo drives implements dual position loop feedback. The drive has interface for two position sensors. In addition, it also has "supplier" specific adjustable parameters for dual loop position control algorithm. In this case, the task of the motion controller is to generate the commanded (desired) motion, and let the servo drive handle the backlash problem using dual position sensors.

A common algorithm is to use the motor encoder for the speed control PID loop as the feedback signal, and the linear encoder for the position control PID loop as the feedback signal. This is just one possible form of the algoithm. There can be many different versions of it.

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