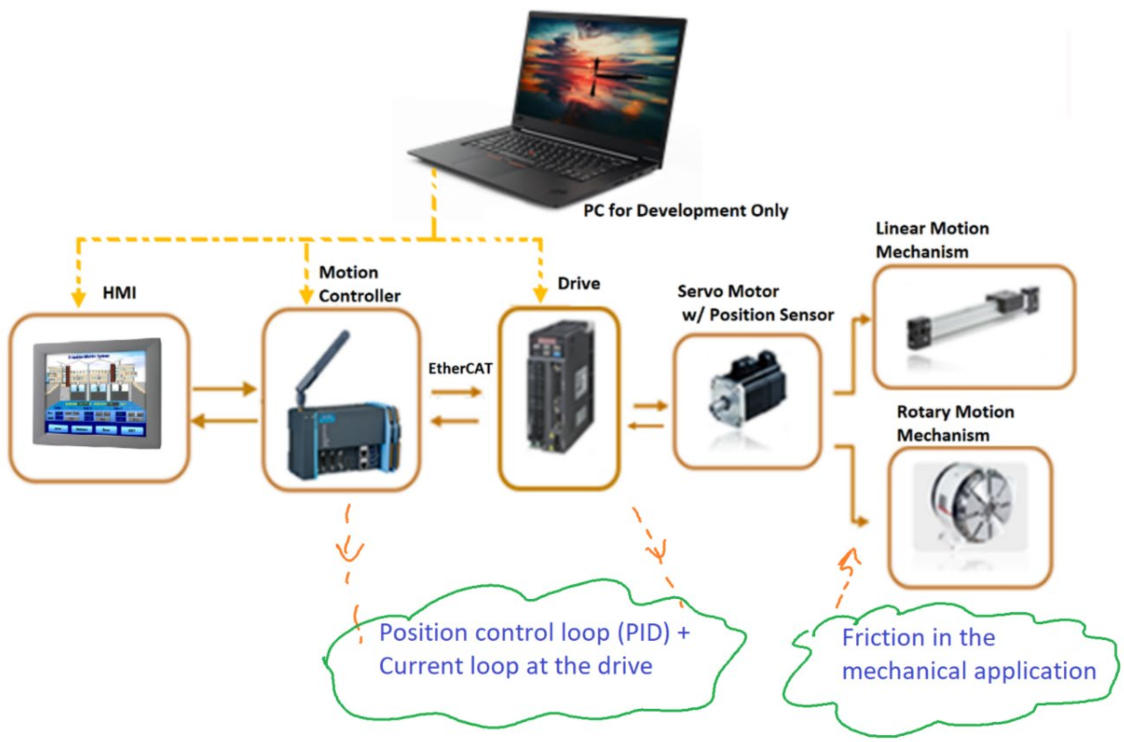
Friction in Motion Control Systems and Its Implications

Friction exists between any two moving objects in contact with each other, i.e. the rotating bearing elements and sleeves in bearings, in screws, gears, sliding stage on a ball-screw or lead-screw driven stage. Friction force (torque), which has stiction and Coulomb friction components, acts as a disturbance load (resistance) to the motion. If it can be measured or estimated, we can compensate for it. But, in reality is is very difficult to accurately measure or estimate friction, hence it is very difficult to directly compensate for it.

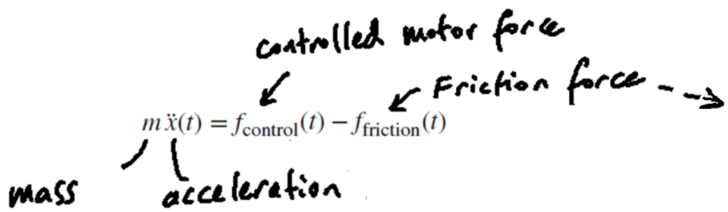


The problem with this kind of friction is that

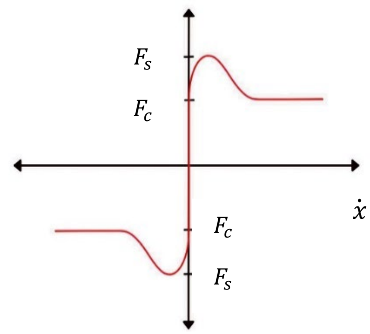
1. Its value varies with operating conditions, such as lubrication condition, load conditions, surface roughness condition, even in between two consecutive repeatative motion.
2. It is rather discontinuous; friction experienced from stationary (zero speed) to just beginning of speed (Stiction Friction) is higher than friction experienced during higher speed motion (Coulomb Friction).

It is not realistic to reliably to predict what the friction force is in real-time. Much research effort has been made over decades for this purpose without much success. Therefore, we can not directly compensate for it via active control software. However, we can measure the positining error, whatever the cause might be and in this case the cause is friction. Then we can try to correct for the error. However, there are limitations on how much we can correct friction caused positining error, even if we can measure the error with high resolution.

Let us consider the positioning error when the commanded speed is zero. In otherwords, servo motion command has a final position command where the servo motor is to stop for a while. Let us consider that we experience F_s stiction friction against motion when motion is stopped and F_cCoulomb friction when the motion just started and that F_s is always larger than F_c and both may vary even in the same system during motion.



$$m\ddot{x}(t) = f_{\text{control}}(t) - f_{\text{friction}}(t)$$



$$f_{\text{control}}(t) < f_{\text{friction}}(t) \Rightarrow \ddot{x}(t) < 0.0 \Rightarrow \dot{x}(t) = 0.0 \ eventually$$

Let us assume we have PD control algorithm for closed loop motion. When the motion is stopped and commanded speed is zero, the PD algorithm will function as P algorithm.

PD control:

$$f_{\text{control}}(t) = K_{\text{p}}e(t) + K_{\text{d}}\dot{e}(t)$$

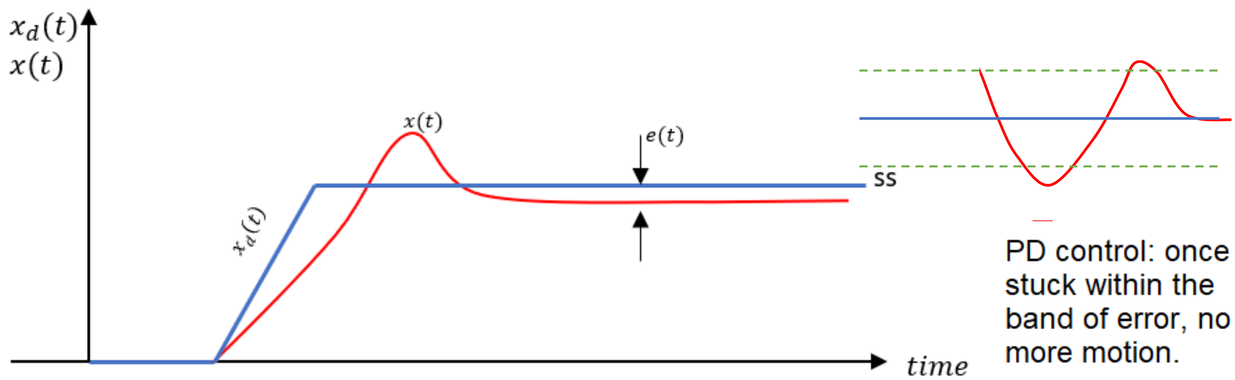
$$f_{\text{control}}(t) = K_{\text{p}}e(t) \quad when \quad \dot{x}(t) = 0.0$$

$$f_{\text{control}}(t) < f_{\text{friction}}(t) \longrightarrow \ddot{x}(t) = 0.0 \quad and \quad \dot{x}(t) = 0.0 \Longrightarrow \quad no\, motion$$

$F_m = K_p * e_p$

Notice that when $F_m < F_s$, the there will not be motion. The force generated by the closed loop servo system is not large enough to break the stiction force. The servo motor will be stuck within the error band of

$$|e_p| < \frac{F_s}{K_p}$$



For a given motion system F_s is determined by the machine conditions. The larger the Stiction friction is, the larger the positioning error band. K_p is the servo algorithm gain but there is a limit as to how large we can make it. Too large values of K_p will invariably lead to unstability or unacceptably large oscillatory motion. As a result, there is a finite error band due to Stiction friction. Notice that if the stuck posiiton is outside this range and $F_m > F_s$, the motion would start and speed up, friction force would drop to F_c , and would stop again around the final desired position. The motion would continue back and forth until the stuck position is within the above defined band, where the generated control force due to positioning error is not large enough the break away from the Stiction friction force.

PID control:

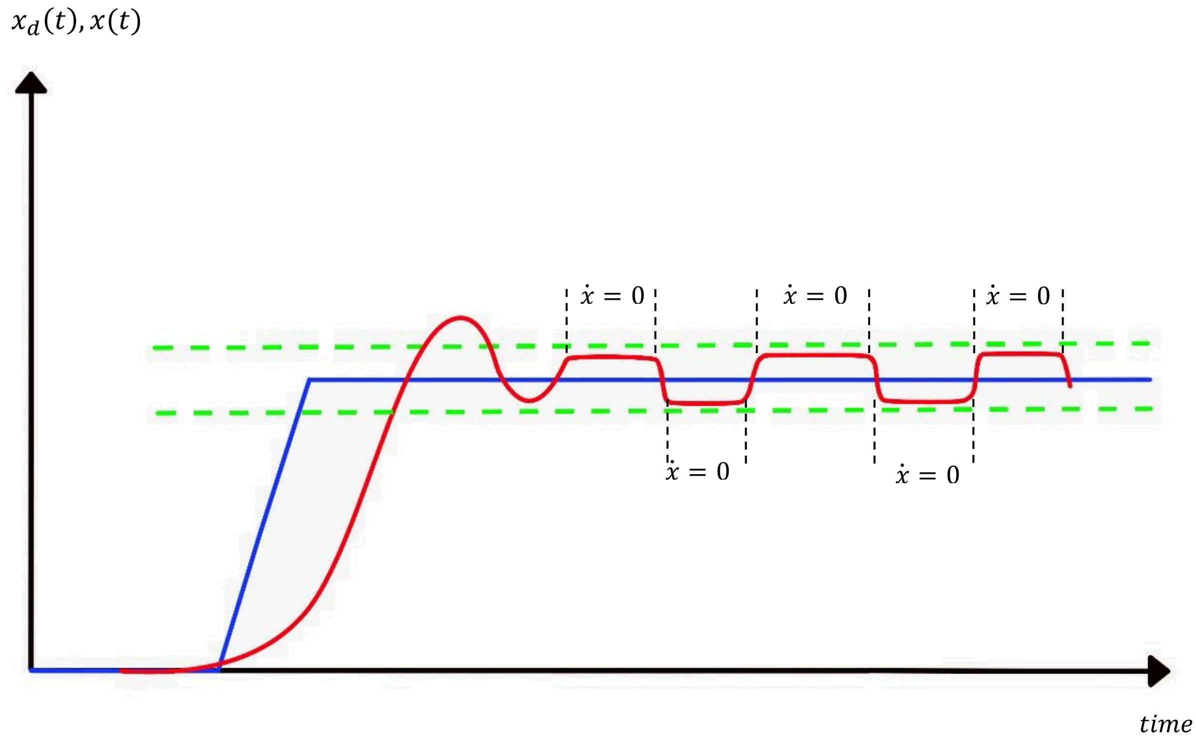
If the servo control algorithm has integral component, PID, the same error band situation exists except that because of the fact that output of the servo algorithm command increases due to integral gain while there is a constant positioning error (stuck position), eventually control is able to break through the stuck position within the error band. Integral gain will eventually make

$F_m > F_s$; when $\dot{x}(t) = 0$, $\dot{x}_d(t) = 0$ ➔ start moving; $\dot{x}(t) != 0$

$$f_{\text{control}}(t) = K_p e(t) + K_d \dot{e}(t) + \int_0^t e(\tau) d\tau$$

Integral control

in a back and forth cyclic oscillation of stuck-wait-move-stuck-wait-move around the final desired position, until or if ever by luck it ends up at the desired position with zero error.



The best way to reduce positioning error due to friction is to reduce the friction mechanically. That is to use high quality components and maintain good lubrication conditions. Simply having higher resolution measurement in sensor feedback and higher resolution torque control does not guarantee us eliminate the friction related positioning errror. The problem is not the control system component resolution. Rather the problem is the variable and sudden change of Stiction and Coulom friction force that feeback control is not able to compensate accurately.

References

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