PID - WHAT IS THIS?

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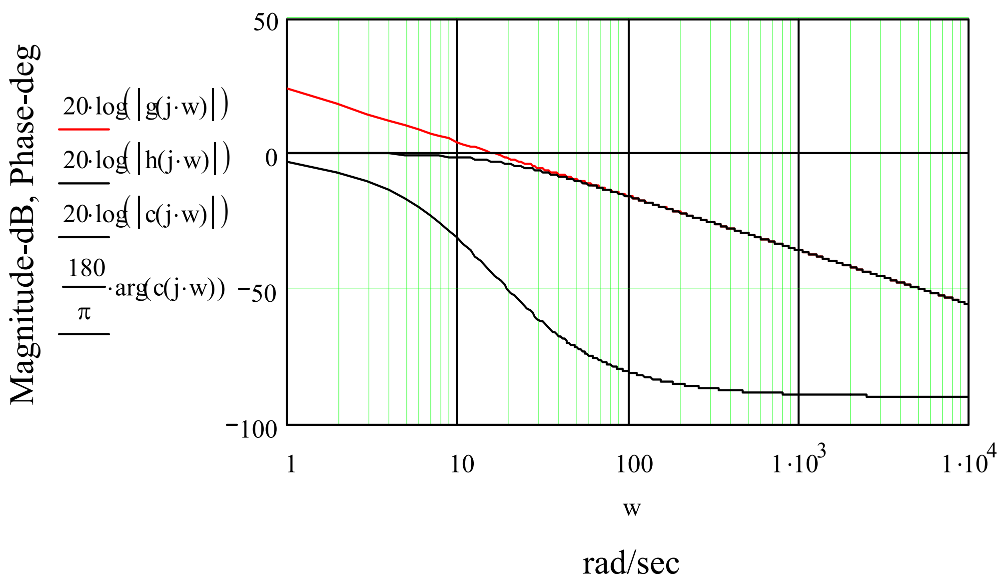
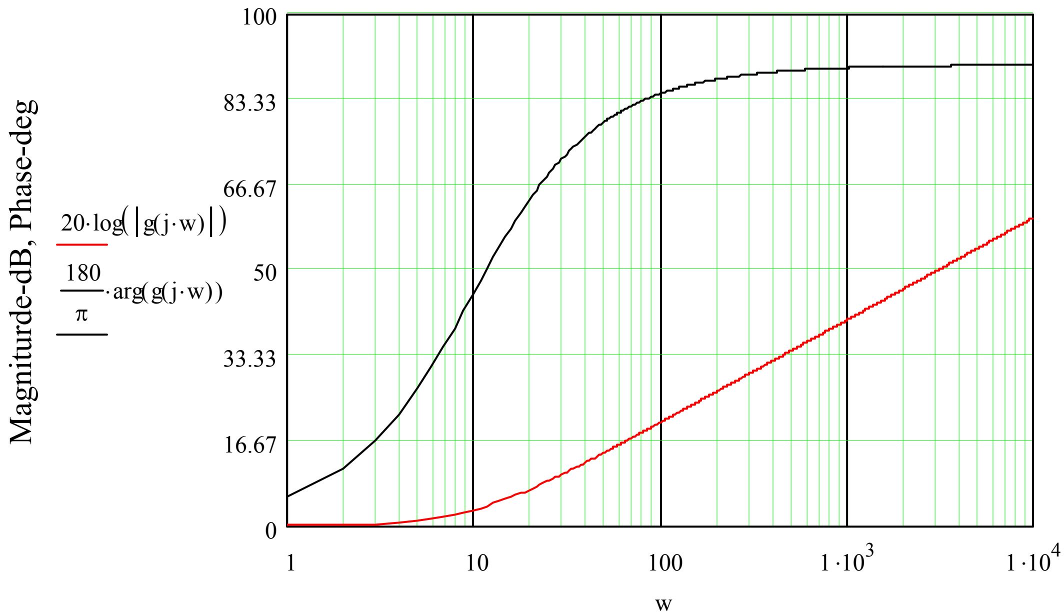
In its simplest terms, PID is a type of control used to stabilize servo drives. PID can be implemented either in analog or digital and be used with hydraulic or electrical servo drives. The process of stabilizing servo drives has been described as an equalization process, or some times referred to as compensation of a servo system. There are two ways to assess servo drives. The first is how *accurate* is the servo drive. PID can increase servo accuracy, especially in a steady state condition (at rest for position and at final velocity for speed). When the gain of a servo is increased, it becomes more accurate. Too much gain, however, will cause it to be unstable and oscillate.

The second assessment method for servo drives is how *stable* will the servo be under its intended modes of operation. A servo drive consists of an amplifier and a motor. In general, if a servo drive, motor and amplifier, are applied to a servo plant (machine) right out of its shipping crate; it will not be optimized. It is then required that compensation be applied to the servo amplifier to optimize and stabilize the drive. Thus the compensation can be thought of as an electrical filter. In the past, these analog circuits were made from operational amplifiers with resistors and capacitors. There are many text books on the use of operational amplifiers. There are typically three types of operational amplifier circuits used to compensate a servo drive. The first type is a straight *gain* function referred to as **proportional (P)** gain. A second type of amplifier circuit has a reducing gain with increasing frequency and is called an **integrator (I) or a lag filter**. A Bode plot or frequency response for an integration at 10 rad/sec is:



Integration at 10 rad/sec

A third type of filter amplifier has an increasing gain with increasing frequency and is called a **differentiator (D) or lead filter**. A Bode plot for a differentiator at 10 rad/sec is:



rad/sec

Differentiation at 10 rad/sec

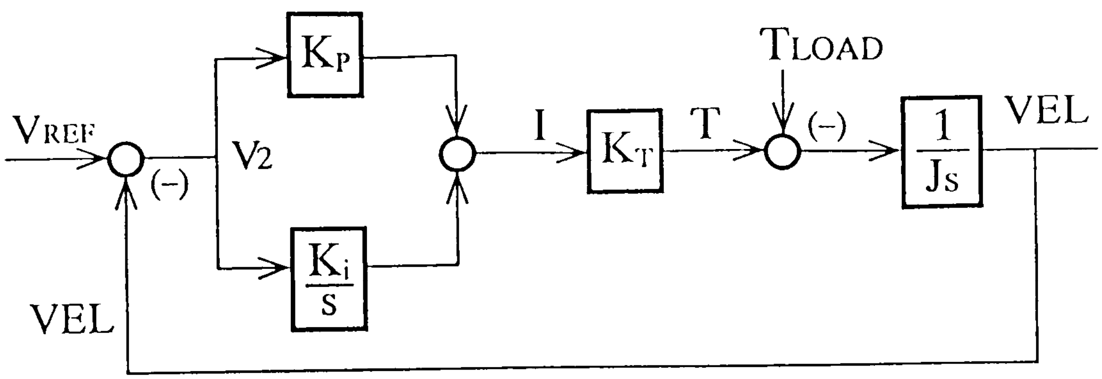
These three types of amplifiers can be used individually or in combination as required. Using a PI filter allows the servo to have its normal (P) gain near the frequency at which it would tend to oscillate, but provides an integrator (I) at frequencies well below the oscillation value. Since an integrator increases gain as the frequency is lowered, this provides the servo loop with much higher gain (and thus accuracy) as it approaches steady state conditions. The differentiator (D) has the opposite effect of an integrator and is inserted at frequencies above the normal oscillation frequency as it tends to have a stabilizing effect. It takes the experience of a trained servo engineer to apply the required servo compensation to have a stable servo drive. With operational amplifier circuits, servo engineers set the compensation by adjusting potentiometers and selecting capacitors. It was something of a trial and error procedure. Today, analysis is performed largely in the frequency domain with the aid of a BODE plot and a set of rules that will guide the servo engineer to achieve desired performance.

There are some rules called indexes of performance that are recommended. The recommended compensation for a position servo loop is proportional (P) compensation, often referred to as a naked servo. If integral compensation (I) is used, the result can be position overshoots on step commands in position. PI and PID compensation can be used with inner velocity servo loops and current servo loops with servo drives. However, it should be cautioned that differential compensation (D) will have ever increasing gain with increasing frequency. This continuing increase in gain will eventually excite various resonances in the servo plant (machine) causing audible noise and/or physical vibration. Thus, it is advisable to cut off the differential compensation (D) about one decade above the servo bandwidth. The bandwidth of the servo is the frequency where the output can no longer follow the input as the input frequency increases, and the output starts to decrease.

Current servo drive technology no longer uses operational amplifiers to compensate servo drives. Digital drives are being used with increasing frequency. Thus the three control blocks P, I, and D are now implemented in firmware. Manufacturers realize the difficulty in selecting the required compensation using the required digital algorithms. Thus today's servo amplifiers have a small dial-in panel on the servo amplifier to dial-in the required drive constants. The P, I, and D constants are entered into the amplifier via dimensionless numbers as recommended by the drive manufacturer. There are no potentiometers or capacitors to adjust. These numbers can then be experimented with to get the desired performance. More advanced servo drives use a *self tune* feature to automatically set the required P, I, and D compensation. There are some procedures in the literature that provide steps to adjust the P, I, and D compensation.

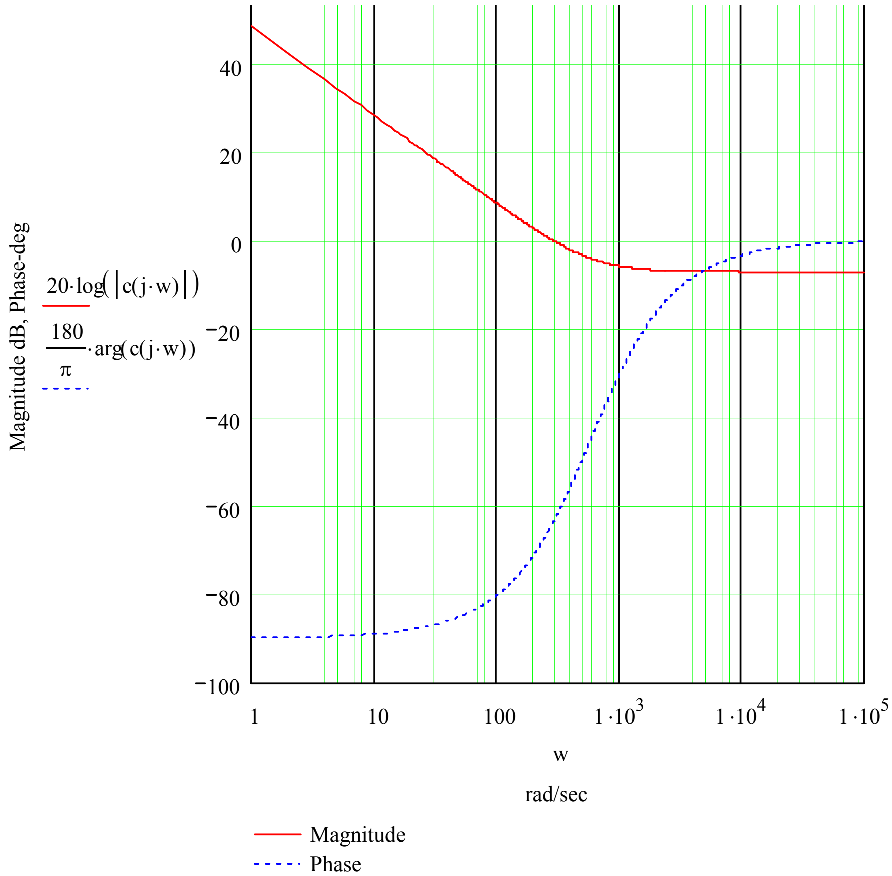
P, I, and D compensation can also be represented with transfer functions and frequency responses.

Most industrial servo drives use proportional plus integral (PI) compensation. The amplifier and PI compensation can be represented as follows:



$$\frac{I}{V_2} = \left[K_p + \frac{K_i}{s}\right] = \frac{K_p s + K_i}{s} = \frac{K_i\left[\frac{K_p}{K_i}s + 1\right]}{s} = \frac{K_2\left[t_2 s + 1\right]}{s}$$

$$t_2 = \frac{K_p}{K_i} \qquad w_2 = \frac{K_i}{K_p} \quad \text{(Corner frequency)}$$



PI Compensation

For those servo engineers and feedback control students, familiar with servo theory, an adjustment procedure follows:

The adjustment of the PI compensation is suggested as-

1. For the uncompensated servo, set the amplifier gain (P) to a value just below the level of instability.

2. It is then required to make a BODE plot or frequency response of the uncompensated servo drive. Note the frequency at –135 degree phase shift (45 degrees phase margin) .

3. From the frequency response for PI compensation, the corner frequency $w_2 = K_i/K_p$ should be approximately 1/10 the -135 degree phase shift frequency. The reason for this is that the attenuation characteristic of the PI controller has a phase lag that is detrimental to the servo phase margin. Thus the corner frequency of the PI compensation should be lowered about one decade or more from the –135 degree phase shift point of the open loop frequency response for the servo drive being compensated. A differentiator is often added near this frequency in order to recover some of this phase lag.

A very good reference on the subject of PI and PID is:

Kuo, B. C., AUTOMATIC CONTROL SYSTEMS, Prentice Hall, 7th edition, 1993