sun hydraulics®

Electro-Proportional Terms and Definitions

Valve Deadband — *The span of operation where there is no flow or pressure output for some specified range of command*

Hydraulic Valve Gain — *The characteristic relating to capacity, where output pressure or flow is compared to input command*

Hysteresis — *The difference of the measured valve output (pressure or flow) between increasing and decreasing command. The value for hysteresis of the valve output is measured at the same command value.*

Linearity — *The characteristic relating to the deviation of output flow or pressure from a straight line, evaluated between 10% and 90% of input command.*

Repeatability — *The variation in output flow or pressure that may exist when the input command is cycled from 0 to the same command, evaluated at 50% and 100% command*

Resolution — *The smallest change in input command that produces a measurable change in output flow or pressure*

Step Response — *The time it takes to reach the expected output flow or pressure from when the input command is applied; evaluated at 100%*

Frequency Response — *The characteristic relating to the maximum speed at which a valve can reasonably operate with an implied accuracy as determined by the gain and phase margins in the Bode analysis*

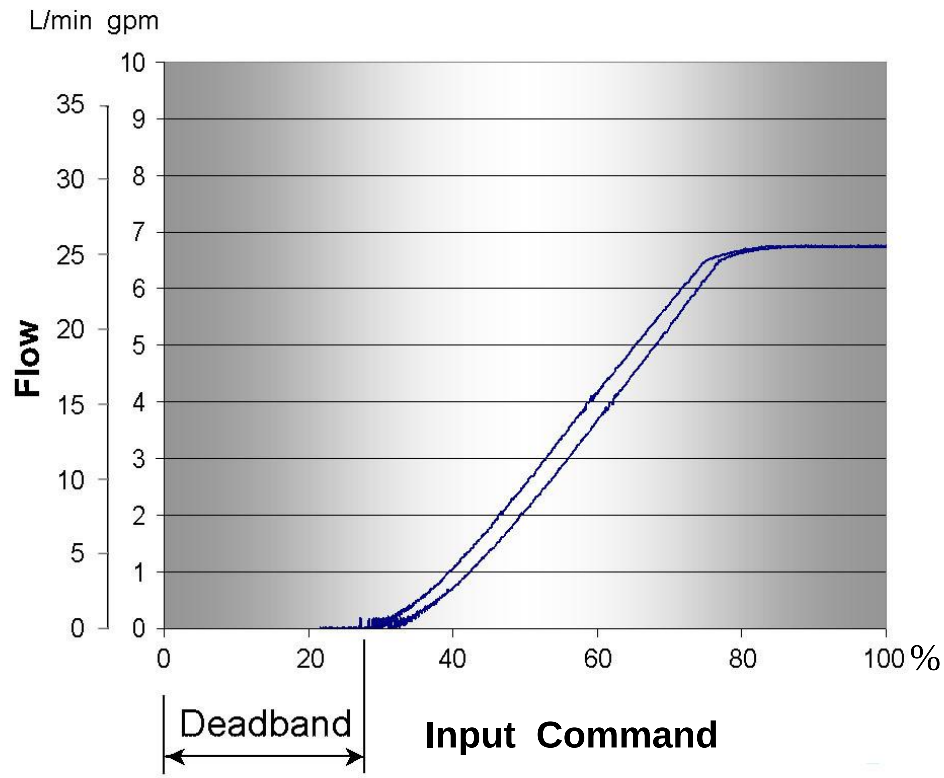
- **Bode Analysis** — *A tool used to evaluate frequency response data from a sinusoidal input to calculate the gain and phase margins used to determine the frequency response*

Valve Deadband *(Normally Closed)*

Defined as, the span of operation where there is no flow or pressure output for some specified range of command.

In Practice

- Very low input commands may produce no flow or pressure output. Input commands must be raised above a certain minimum before flow or pressure begins to change. This characteristic can be countered and managed by electronic control.
- For Sun cartridges, deadband is the result of spool overlap (intentionally designed into the valve to minimize leakage). As command to the solenoid is increased, the spool starts to move but there is no increase in effective orifice size.
- Deadband values typically represent 25% of the command signal, however, because of tolerance variation, location of metering edges, and spring variation, the 25% has a tolerance of 10%.
- Note: Deadband may be balanced on a valve-to-valve basis via the amplifier's electronics.
- Spool leakage, when closed, is less than 5 in^3/min. at 3000 psi differential pressure.

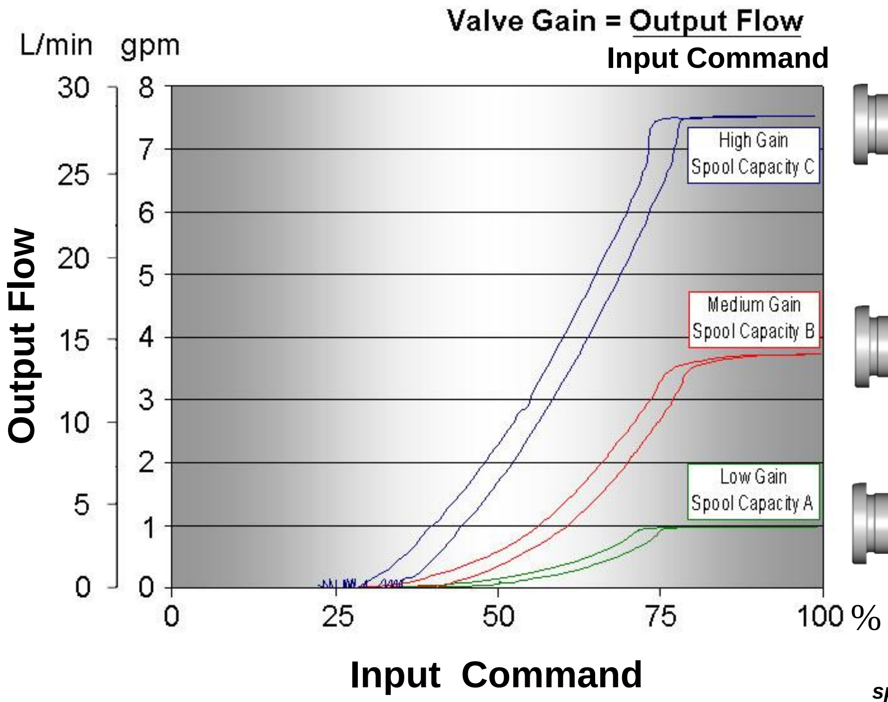


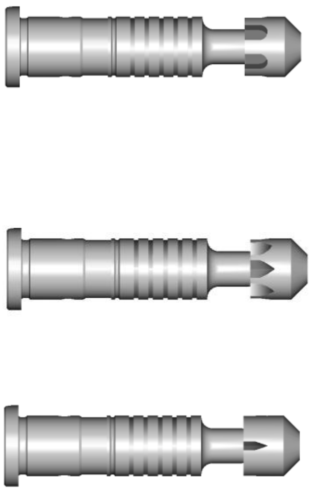
Hydraulic Valve Gain *Proportional Throttle*

Defined as, the characteristic relating to capacity, where output pressure or flow is compared to input command.

In Practice

- Different gains are used to increase the precision of the control resolution. Good control resolution aids in the repeatability and the overall measure of valve accuracy.
- In order to enhance the performance and accuracy of proportional throttles, Sun offers 4 different capacity range spools; 1.5, 3.5, 7, 10 gpm (6, 14, 28, 40 L/min.) nominal. These flows are established at a pressure differential of 200 psi as established with a pressure compensator.
- Spool gain options are available in both normally closed and normally open models.





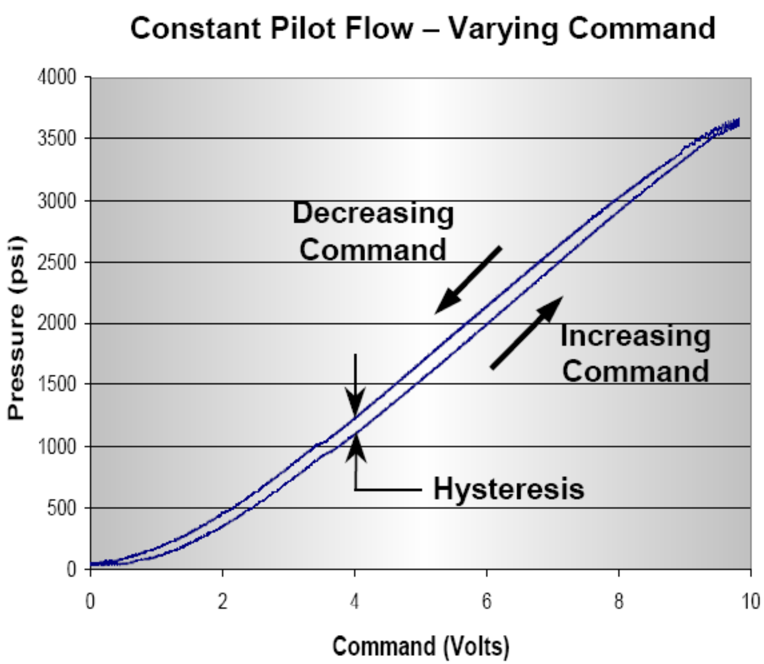
Normally closed spools shown above

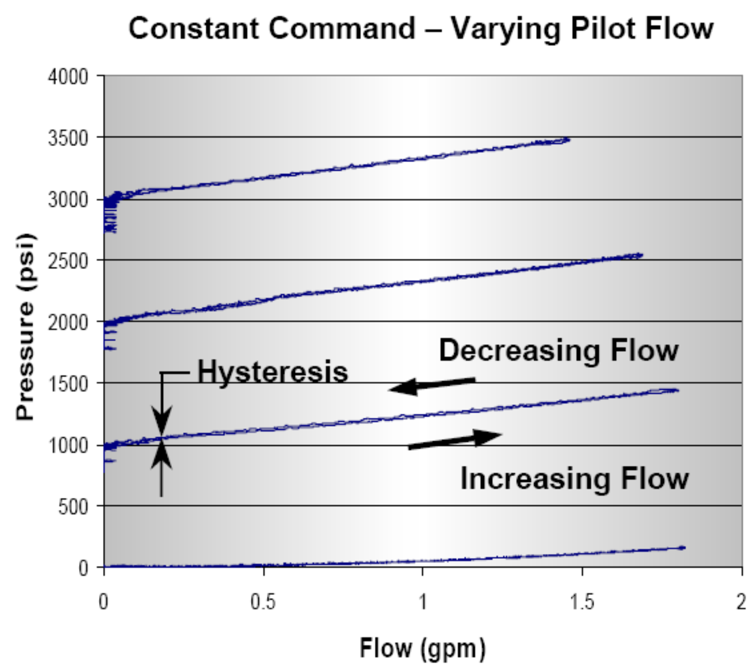
Hysteresis

Defined as, the difference of the measured valve output (pressure or flow) between increasing and decreasing command. The value for hysteresis of the valve output is measured at the same command value.

In Practice

- Valve hysteresis is primarily the result of mechanical friction within the valve but is also the result of magnetic hysteresis and fluid dynamics. Hysteresis is not necessarily a bad thing.
- Unexpected flows and pressures may result if hysteresis is not considered in the electronic control scheme.





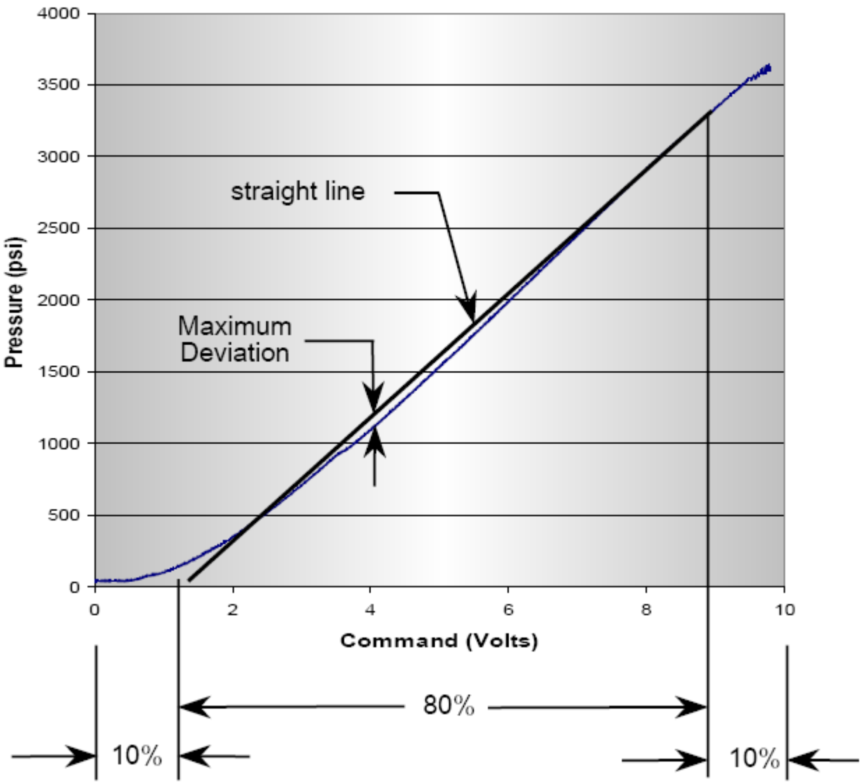
In both instances, the percent of hysteresis is expressed as the difference between the increasing and decreasing pressure divided by the maximum output.

Linearity

Defined as, the characteristic relating to the deviation of output flow or pressure from a straight line, evaluated between 10% and 90% of input command.

In Practice

- The deviation of the command vs. pressure curve from a straight line between the 10% and 90% values expressed as a percentage of the pressure range defines the linearity of the valve.
- The 10% values are selected based upon the operational range of the valve.
- Linearity is useful in order to have predictable valve performance with simple control systems.
- The linearity of the valve has a direct relationship to the accuracy of the valve in an open loop system since the output pressure is directly proportional to the input signal within the stated accuracy limits.
- It is often possible to linearize non-linear valves through sophisticated control systems.

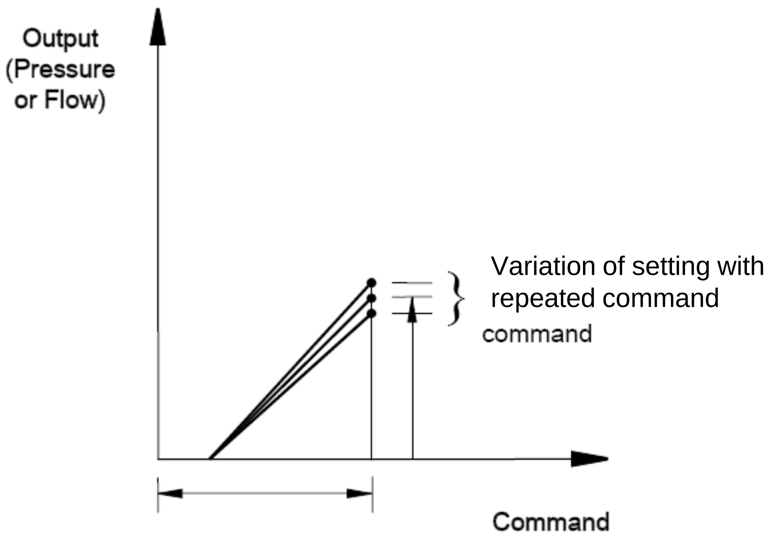


Repeatability

Defined as, the variation in output pressure or flow that may exist when the input command is cycled from 0 to the same command, evaluated at 50% and 100% command.

In Practice

- Repeatability is expressed in percentage of the maximum flow or pressure range.
- Repeatability is used an the overall measure of the valve accuracy.
- As with response testing, the test set-up and in particular, the drive electronics, contribute greatly to repeatability.

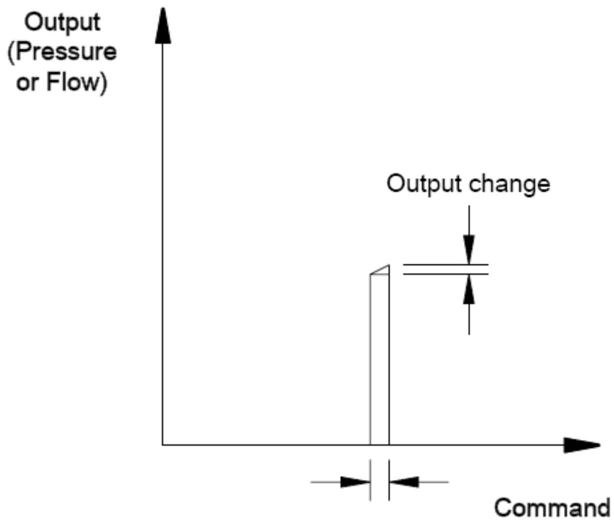


Resolution

Defined as, the smallest change in input command that produces a measurable change in output flow or pressure.

In Practice

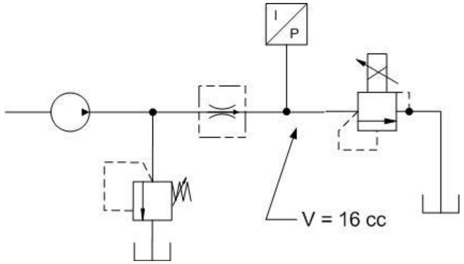
- Resolution is also applied to the drive electronics and is a function of the bit count of the microprocessor and analog-to-digital conversion chip.



Smallest change in command which produces a measurable change in output.

Step Response

Defined as, the time it takes to reach the expected output pressure or flow from when the input command is applied; commonly evaluated at 100%.

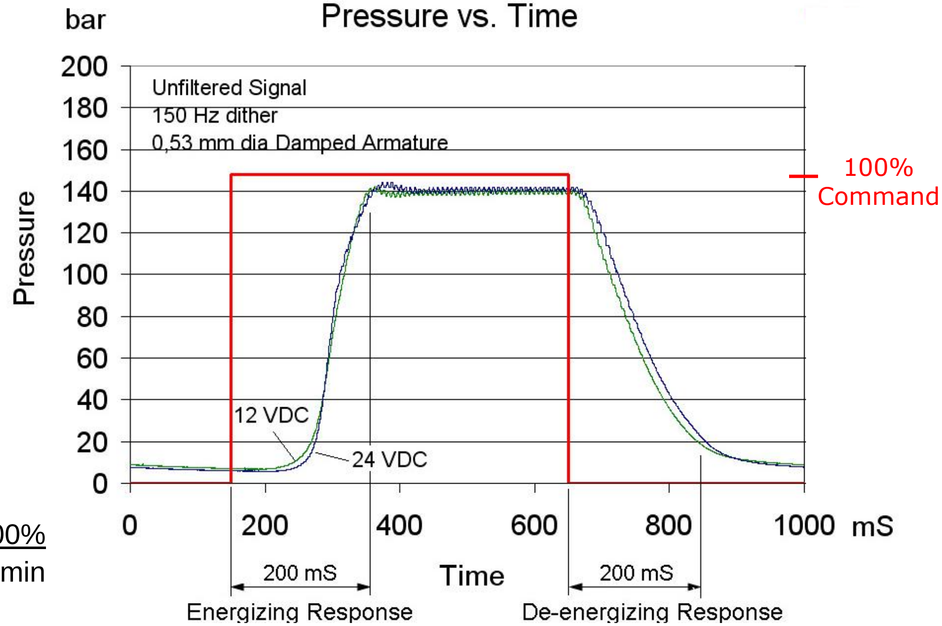


In Practice

- Step response is a measure which can provide the relative speed in which a valve can operate.
- Step response can be influenced by the hydraulic test set-up and driving electronics. Published values should be used as reference only unless specific details of the testing are included.
- Step response at Sun has traditionally been evaluated at 100% command step and 100% of the intended response (evaluated before over shoot and under shoot, e.g. ringing). This method is commonly used throughout the industry.

Model RBAP-XAN

Pressure vs. Time



<u>Command – 0% to 100%</u>

Flow Rate 0,4 l/min

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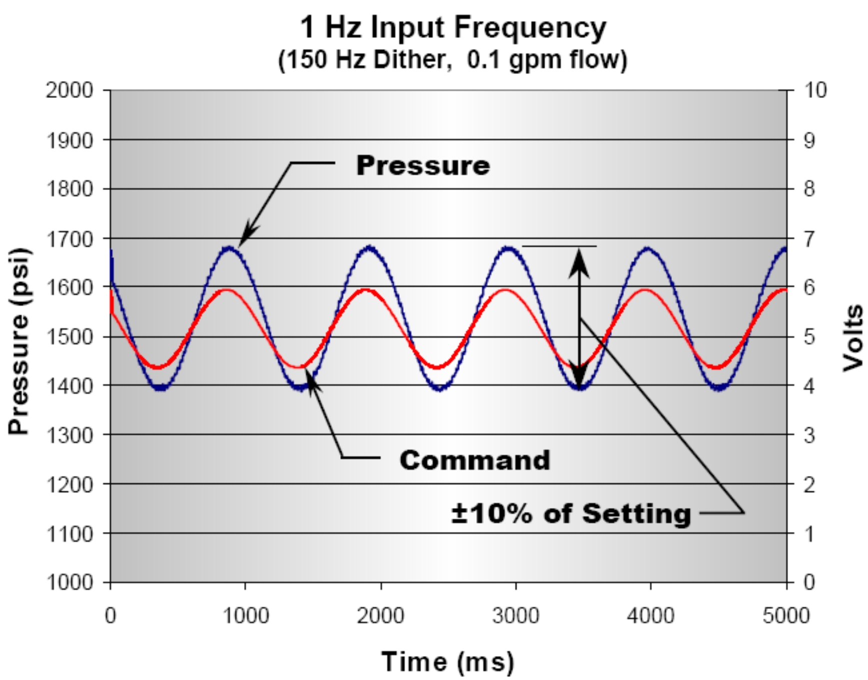
Frequency Response

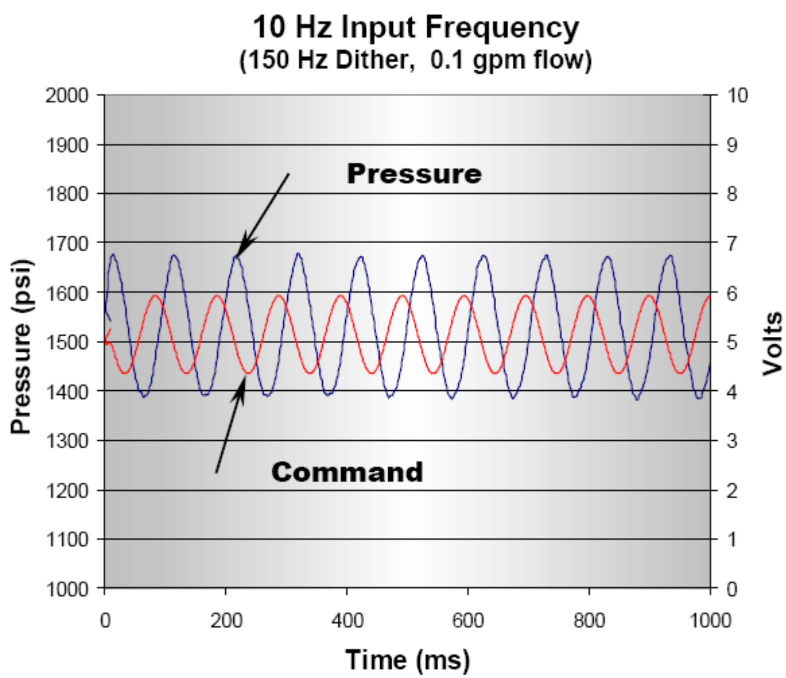
Defined as, the characteristic relating to the maximum speed at which a valve can reasonably operate with an implied accuracy as determined by the gain and phase margins in the Bode analysis.

In Practice

- Frequency response is an important measure for those designing highly dynamic systems which require a fast-acting valve to achieve the desired system performance. Frequency response testing is generally performed around a mid-point of operation and with operation at ±10%, ±20%, and up to ±100% by some manufacturers.
- Like step response, frequency response can be influenced by the hydraulic test set-up and driving electronics. Published values should be used as reference only unless specific details of the testing are included.



With low frequency, input command and output pressure remain in phase. Output pressure rises fully.



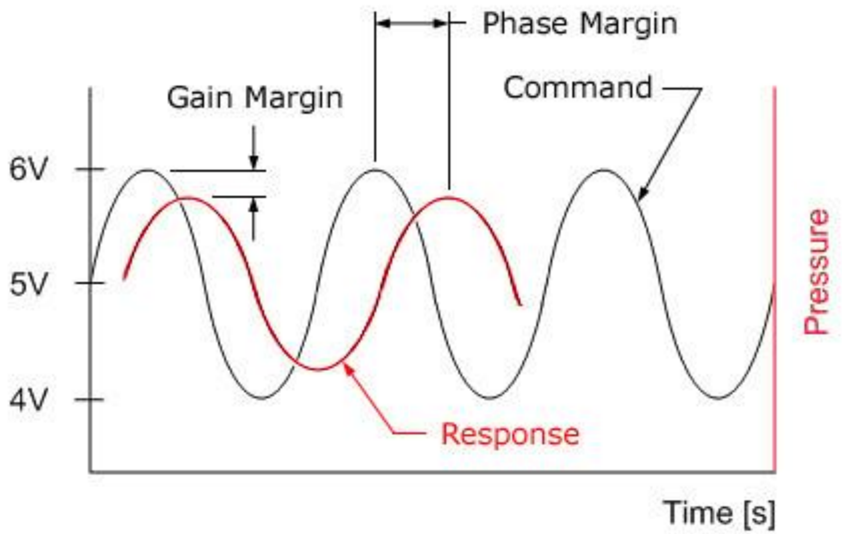
With high frequency, output pressure lags input command. Output pressure does not rise fully.

Bode Analysis Refresher

Defined as, a tool used to evaluate frequency response data from a sinusoidal input to calculate the gain and phase margins used to determine the frequency response.

In Practice

The Bode plot is an analysis tool to determine frequency response when the valve is commanded with a sine wave. The key measures are gain margin and phase margin. Gain margin is a measure of the amplitude of the response of the valve compared to the commanded value and is expressed in decibels. A decibel is a way to normalize the data.



Bode Analysis Refresher *Continued*

In Practice

The key point for hydraulic valves is -3 dB, which means that the response of the valve is 71% of the commanded value. Phase margin is a measure of how well the valve is tracking in time the commanded value. Phase margin is measured in degrees and can either be leading the command value (very unlikely in hydraulic valves) or lagging (more common in hydraulic valves). The key point of phase margin is -90º, which means the valve response is lagging the command by 90º.

$$\text{Gain Margin [dB]} = 20\ \text{Log10}\ \left(\frac{\text{Response Amplitude}}{\text{Baseline Amplitude}}\right)$$

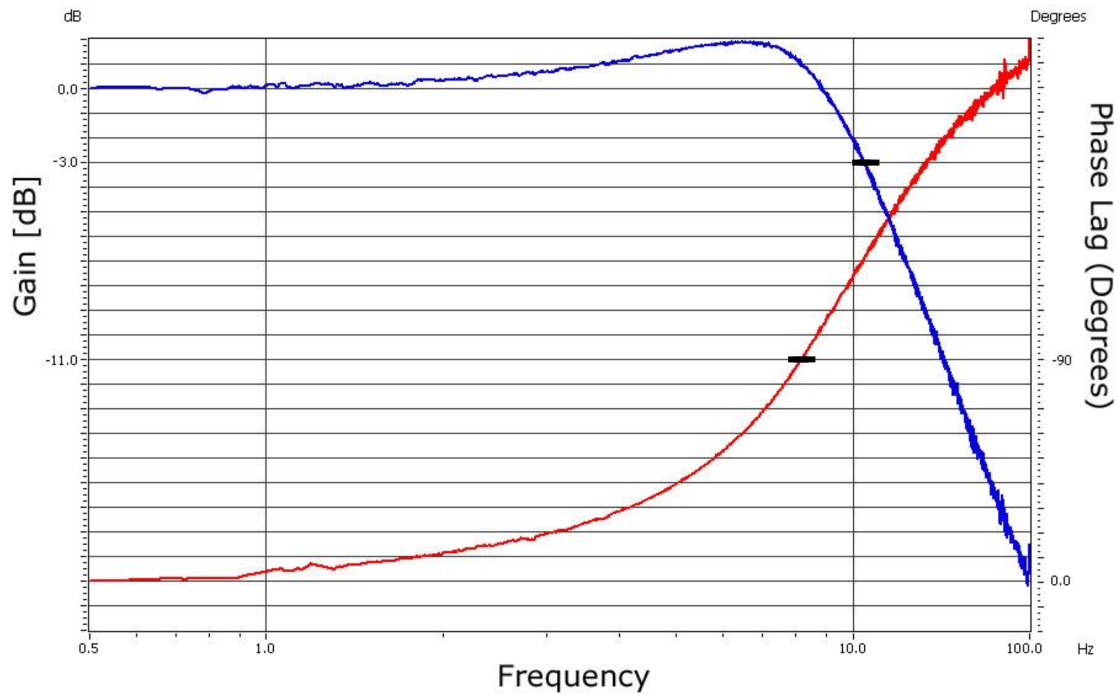
*** Base line amplitude is the response amplitude at very low frequency**

$$\text{Phase Margin [Degrees]} = \left(\frac{\text{360 Degrees}}{\text{1Hz}}\right)\left(\text{Frequency}_{\text{Base Line Peak}} - \text{Frequency}_{\text{Response Peak}}\right)$$

Bode Analysis Refresher *Continued*

In Practice

The key point of phase margin is -90º, which means the valve response is lagging the command by 90º. From the Bode plot, these values are located and referenced to the frequency on the x-axis. The lower of the two frequencies is the frequency response of the valve. Keep in mind that with Bode analysis, the response of the valve is in the frequency domain and with step response the response is in the time domain.



-3db → 70.8% Original Amplitude, Normally Shown on Semi-log Graph