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Methodology of PID Control – A Case Study for Servomotors

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ABSTRACT

Literally, the so-called three terms controller PID, has been extensively used in industrial applications for programming moving systems behavior. Given the fact that it is still in use, this paper will emphasize in the cooperation between such a controller and a very commonly used actuator, the servomotors. There is an introductory part which explains both parties operational characteristics and at the end a specific example of their use is illustrated.

Keywords

Classical control, PID tuning, servo motor applications

1. INTRODUCTION

Servo motors are specially designed motors to be used in control applications and robotics. They are used for precise position and speed control at high torques. It consists of a suitable motor, position sensor and a sophisticated controller. Servo motors can be characterized according the motor controlled by servomechanism, i.e. if DC motor is controlled using servomechanism, it is called as DC Servo motor. Thus major types of Servo motor may be - DC Servo motor, AC Servo motor.

Servo motors are available in power ratings from fraction of watt upto few 100 watts. They are having high torque capabilities. The rotor of servo motor is made smaller in diameter and longer in length, so that it has low inertia.

2. PROPOSED ALGORITHM

2.1 How does it work?

Servos are controlled by sending them a pulse of variable width. The control wire is used to send this pulse. The parameters for this pulse are that it has a minimum pulse, a maximum pulse, and a repetition rate. Given the rotation constraints of the servo, neutral is defined to be the position where the servo has exactly the same amount of potential rotation in the clockwise direction as it does in the counter clockwise direction. It is important to note that different servos will have different constraints on their rotation but they all have a neutral position, and that position is always around 1.5 milliseconds (ms).

The angle is determined by the duration of a pulse that is applied to the control wire. This is called Pulse width Modulation. The servo expects to see a pulse every 20 ms. The length of the pulse will determine how far the motor turns. For example, a 1.5 ms pulse will make the motor turn to the 90 degree position (neutral position).

Fig. 1. DWT Decomposition model

When these servos are commanded to move they will move to the position and hold that position. If an external force pushes against the servo while the servo is holding a position, the servo will resist from moving out of that position. The maximum amount of force the servo can exert is the torque rating of the servo. Servos will not hold their position forever though; the position pulse must be repeated to instruct the servo to stay in position.

When a pulse is sent to a servo that is less than 1.5 ms the servo rotates to a position and holds its output shaft some number of degrees counterclockwise from the neutral point. When the pulse is wider than 1.5 ms the opposite occurs. The minimal width and the maximum width of pulse that will command the servo to turn to a valid position are functions of each servo. Different brands, and even different servos of the same brand, will have different maximum and minimums. Generally the minimum pulse will be about 1 ms wide and the maximum pulse will be 2 ms wide.

Another parameter that varies from servo to servo is the turn rate. This is the time it takes from the servo to change from one position to another. The worst case turning time is when the servo is holding at the minimum rotation and it is commanded to go to maximum rotation. This can take several seconds on very high torque servos.

2.2 Where is servo motor used

Robotics: A servo motor at every "joint" of a robot is used to actuate movements, giving the robot arm its precise angle.

Conveyor Belts: Servo motors move, stop, and start conveyor belts carrying product along to various stages, for example, in product packaging/bottling, and labeling.

Camera Auto Focus: A highly precise servo motor built into the camera corrects a camera's lens to sharpen out-of-focus images.

Robotic Vehicle: Commonly used in military applications and bomb detonation, servo motors control the wheels of the robotic vehicle, generating enough torque to move, stop, and start the vehicle smoothly as well as control its speed.

Solar Tracking System: Servo motors adjust the angle of solar panels throughout the day so that each panel continues to face the sun, harnessing maximum energy from sunup to sundown.

Metal Cutting & Metal Forming Machines: Servo motors provide precise motion control for milling machines, lathes, grinding, centering, punching, pressing, and bending in metal fabrication for such items as jar lids to automotive wheels.

Antenna Positioning: Servo motors are used on both the azimuth and elevation drive axis of antennas and telescopes such as those used by the National Radio Astronomy Observatory. (NRAO).

Woodworking/CNC: Servo motors control woodturning mechanisms (lathes) that shape table legs and stair spindles, for example, as well as augering and drilling the holes necessary for assembling those products later in the process.

Textiles: Servo motors control industrial spinning and weaving machines, looms, and knitting machines that produce textiles such as carpeting and fabrics as well as wearable items such as socks, caps, gloves, and mittens.

Printing Presses/Printers: Servo motors stop and start the print heads precisely on the page as well as move paper along to print multiple rows of text or graphics in exact lines, whether it's a newspaper, a magazine, or an annual report.

Automatic Door Openers: Supermarkets and hospital entrances are prime examples of automated door openers controlled by servo motors, whether the signal to open is via push plate beside the door for handicapped access or by radio transmitter positioned overhead.

2.3 Servo motor pros and cons

Advantages:

High output power relative to motor size and weight.

Encoder determines accuracy and resolution.

High efficiency. Can approach 90% at light loads.

High torque to inertia ratio. Can rapidly accelerate loads.

Has "reserve" power. 2-3 times continuous power for short periods.

Has "reserve" torque. 5-10 times rated torque for short periods.

Motor stays cool. Current draw proportional to load.

Usable high speed torque. Maintains rated torque to 90% of NL RPM

Audibly quiet at high speeds.

Resonance and vibration free operation.

Disadvantages (brush type):

Requires "tuning" to stabilize feedback loop.

Motor "runs away" when something breaks. Safety circuits required.

Complex. Requires encoder.

Brush wear limits life to 2,000 hrs. Service is then required.

Peak torque is limited to a 1% duty cycle.

Motor can be damaged by sustained overload.

Bewildering choice of motors, encoders, servo drives.

Power supply current 10 times average to use peak torque. See (5).

Motor develops peak power at higher speeds. Gearing often required.

Poor motor cooling. Ventilated motors are easily contaminated.

III. PID CONTROLLER

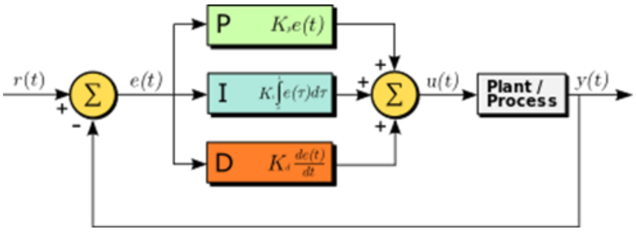

Fig. 2.

Proportional-Integral-Derivative (PID) control is the most common control algorithm used in industry and has been universally accepted in industrial control. The popularity of PID controllers can be attributed partly to their robust performance in a wide range of operating conditions and partly to their functional simplicity, which allows engineers to operate them in a simple, straightforward manner.

2.4 Basics

The basic idea behind a PID controller is to read a sensor, then compute the desired actuator output by calculating proportional, integral, and derivative responses and summing those three components to compute the output. Before we start to define the parameters of a PID controller, we shall see what a closed loop system is and some of the terminologies associated with it.

2.5 Closed Loop System

In a typical control system, the process variable is the system parameter that needs to be controlled, such as temperature (ºC), pressure (psi), or flow rate (liters/minute). A sensor is used to measure the process variable and provide feedback to the control system. The set point is the desired or command value for the process variable, such as 100 degrees Celsius in the case of a temperature control system. At any given moment, the difference between the process variable and the set point is used by the control system algorithm (compensator), to determine the desired actuator output to drive the system (plant). For instance, if the measured temperature process variable is 100 ºC and the desired temperature set point is 120 ºC, then the actuator output specified by the control algorithm might be to drive a heater. Driving an actuator to turn on a heater causes the system to become warmer, and results in an increase in the temperature process variable. This is called a closed loop control system, because the process of reading sensors to provide constant feedback and calculating the desired actuator output is repeated continuously and at a fixed loop rate.

In many cases, the actuator output is not the only signal that has an effect on the system. For instance, in a temperature chamber there might be a source of cool air that sometimes blows into the chamber and disturbs the temperature. Such a term is referred to as disturbance. We usually try to design the control system to minimize the effect of disturbances on the process variable.

2.6 Definition of Terminologies

The control design process begins by defining the performance requirements. Control system performance is often measured by applying a step function as the set point command variable, and then measuring the response of the process variable. Commonly, the response is quantified by measuring defined waveform characteristics. Rise Time is the amount of time the system takes to go from 10% to 90% of the steady-state, or final, value. Percent Overshoot is the amount that the process variable overshoots the final value, expressed as a percentage of the final value. Settling time is the time required for the process variable to settle to within a certain percentage (commonly 5%) of the final value. Steady-State Error is the final difference between the process variable and set point. Note that the exact definition of these quantities will vary in industry and academia.

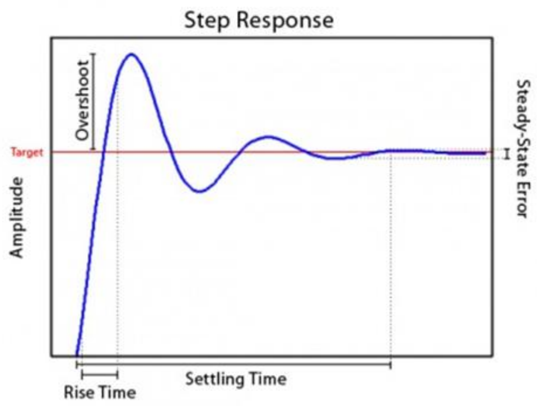

Fig. 3.

After using one or all of these quantities to define the performance requirements for a control system, it is useful to define the worst case conditions in which the control system will be expected to meet these design requirements. Often times, there is a disturbance in the system that affects the process variable or the measurement of the process variable. It is important to design a control system that performs satisfactorily during worst case conditions. The measure of how well the control system is able to overcome the effects of disturbances is referred to as the disturbance rejection of the control system.

In some cases, the response of the system to a given control output may change over time or in relation to some variable. A nonlinear system is a system in which the control parameters that produce a desired response at one operating point might not produce a satisfactory response at another operating point. For instance, a chamber partially filled with fluid will exhibit a much faster response to heater output when nearly empty than it will when nearly full of fluid. The measure of how well the control system will tolerate disturbances and nonlinearities is referred to as the robustness of the control system.

Some systems exhibit an undesirable behavior called deadtime. Deadtime is a delay between when a process variable changes, and when that change can be observed. For instance, if a temperature sensor is placed far away from a cold water fluid inlet valve, it will not measure a change in temperature immediately if the valve is opened or closed. Deadtime can also be caused by a system or output actuator that is slow to respond to the control command, for instance, a valve that is slow to open or close. A common source of deadtime in chemical plants is the delay caused by the flow of fluid through pipes.

Loop cycle is also an important parameter of a closed loop system. The interval of time between calls to a control algorithm is the loop cycle time. Systems that change quickly or have complex behavior require faster control loop rates.

Once the performance requirements have been specified, it is time to examine the system and select an appropriate control scheme. In the vast majority of applications, a PID control will provide the required results.

2.7 PID meaning

Proportional Response

The proportional component depends only on the difference between the set point and the process variable. This difference is referred to as the Error term. The proportional gain (Kc) determines the ratio of output response to the error signal. For instance, if the error term has a magnitude of 10, a proportional gain of 5 would produce a proportional response of 50. In general, increasing the proportional gain will increase the speed of the control system response. However, if the proportional gain is too large, the process variable will begin to oscillate. If Kc is increased further, the oscillations will become larger and the system will become unstable and may even oscillate out of control.

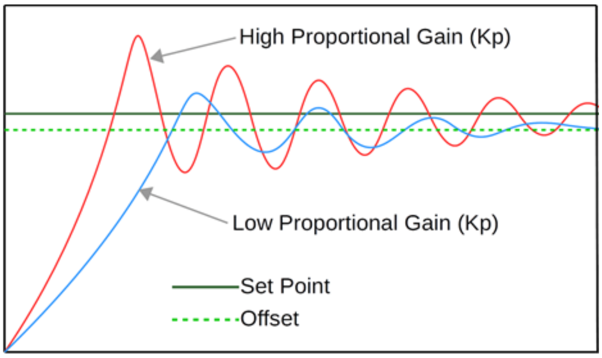

Fig. 4. Integral Response

The integral component sums the error term over time. The result is that even a small error term will cause the integral component to increase slowly. The integral response will continually increase over time unless the error is zero, so the effect is to drive the Steady-State error to zero. Steady-State error is the final difference between the process variable and set point. A phenomenon called integral windup results when integral action saturates a controller without the controller driving the error signal toward zero.

Derivative Response

The derivative component causes the output to decrease if the process variable is increasing rapidly. The derivative response is proportional to the rate of change of the process variable. Increasing the derivative time (Td) parameter will cause the control system to react more strongly to changes in the error term and will increase the speed of the overall control system response. Most practical control systems use very small derivative time (Td), because the Derivative Response is highly sensitive to noise in the process variable signal. If the sensor feedback signal is noisy or if the control loop rate is too slow, the derivative response can make the control system unstable.

2.8 Tuning

The process of setting the optimal gains for P, I and D to get an ideal response from a control system is called tuning. There are different methods of tuning of which the "guess and check" method and the Ziegler Nichols method will be discussed.

The gains of a PID controller can be obtained by trial and error method. Once an engineer understands the significance of each gain parameter, this method becomes relatively easy. In this method, the I and D terms are set to zero first and the proportional gain is increased until the output of the loop oscillates. As one increases the proportional gain, the system becomes faster, but care must be taken not make the system unstable. Once P has been set to obtain a desired fast response, the integral term is increased to stop the oscillations. The integral term reduces the steady state error, but increases overshoot. Some amount of overshoot is always necessary for a fast system so that it could respond to changes immediately. The integral term is tweaked to achieve a minimal steady state error. Once the P and I have been set to get the desired fast control system with minimal steady state error, the derivative term is increased until the loop is acceptably quick to its set point. Increasing derivative term decreases overshoot and yields higher gain with stability but would cause the system to be highly sensitive to noise. Often times, engineers need to tradeoff one characteristic of a control system for another to better meet their requirements.

3. ACKNOWLEDGMENTS

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