# Posicast Control Past and Present

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***Abstract*—Renewed attention to Posicast control has spawned new feedback based approaches and applications for what was orignally a feedforward control technique. In this paper, the basic principles of Posicast control, some of its past history, and new methods and fields of application are presented.**

***Index Terms*—Posicast, input preshaping**

## I. The Basic Concept

INVENTED in the late 1950's, Posicast is a feedforward control method that dampens oscillations in systems whose other transient specifications are otherwise acceptable. When properly tuned, the controlled system yields a transient response that has deadbeat nature.

Consider a system having a lightly damped step response as shown in Fig. 1(a). The overshoot in the response can be described by two parameters. First, the time to the first peak is one half the underdamped response period $T_d$. Second, the peak value is described by $1 + \delta$, where $\delta$ is the normalized overshoot, which ranges from zero to one. Zero overshoot corresponds to critical damping.

Posicast splits the original step input command into two parts, as illustrated in Fig. 1(b). The first part is a scaled step that causes the first peak of the oscillatory response to precisely meet the desired final value. The second part of the reshaped input is full scale and time-delayed to precisely cancel the remaining oscillatory response, thus causing the system output to stay at the desired value. Such is the idea behind "half-cycle Posicast," which can be modeled using just the two parameters $\delta$ and $T_d$. The resulting system output is sketched in Fig. 1(c); the uncompensated output is also shown for comparison.

Another description of half-cycle Posicast follows the example originally presented by Smith [1] and Cook [2]. Consider the problem of moving a load suspended by a cable attached to a gantry. The sequence of movements is illustrated in Fig. 2. In the uppermost frame A, the gantry and the load are both at position '1.' The motion starts in the second frame B, with the gantry moving and then stopping at postion '2,' thus causing the load to swing toward position 3. In the third frame C, the load has swung past the gantry to position '3,' and is about to swing back. Finally, in frame D, the gantry immediately moves to position '3,' so that the load stays at position 3 without overshoot or oscillations.

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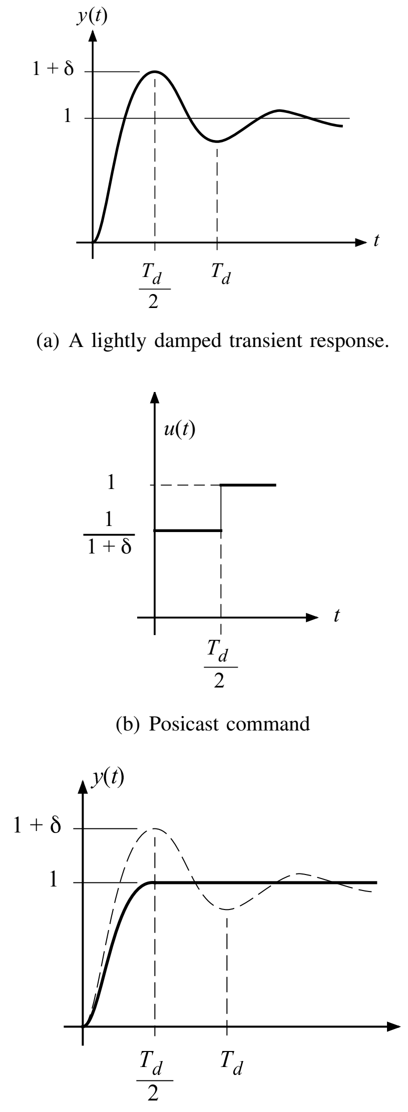
Publisher Identification Number 1558-7908-022007_01




(a) A lightly damped transient response.

(b) Posicast command

(c) System output (dashed is uncompensated)

Fig. 1. Natural response (a), Posicast command (b) and resulting output (c)

### A. The Analytical Model of Posicast

One block diagram interpretation of the half-cycle Posicast controller is shown in Fig. 3(a). The model has two forward paths. The upper path is that of the original, uncompensated command input. In the lower path, a portion of the original command is initially subtracted, so that the peak of the response will not overshoot the desired final value. Precisely

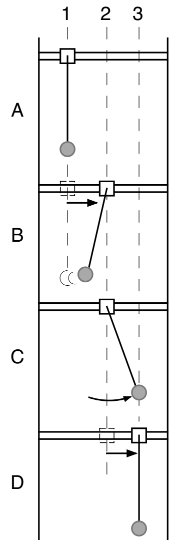
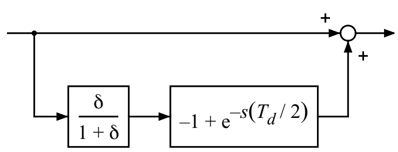
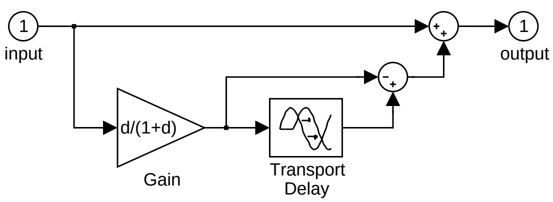



Fig. 2. Explaining half-cycle Posicast using the gantry problem.




(a) Transfer function form




(b) SIMULINK diagram

Fig. 3. Block diagrams for half cycle Posicast

a half cycle later, the command is fully restored to cancel oscillations and maintain the final value. The transfer function is given by the function $1 + P(s)$, where $P(s)$ is given by:

$$P(s) = \frac{\delta}{1+\delta}\left[-1 + e^{-s(T_d/2)}\right] \tag{1}$$

Posicast can be easily constructed in MATLAB's SIMULINK environment by using the transport delay block. A sample diagram is shown in Fig. 3(b)

### *B. Frequency Domain Analysis of Posicast*

Half-cycle Posicast is equivalent to an all-zero filter, with an infinite set of zeros spaced at odd multiples of the damped natural frequency [2], [3]. Solving for the roots of $1+P(s) = 0$, the real part of the zeros is given by:

$$\text{Real part } = -\frac{2}{T_d}\ln\delta \tag{2}$$

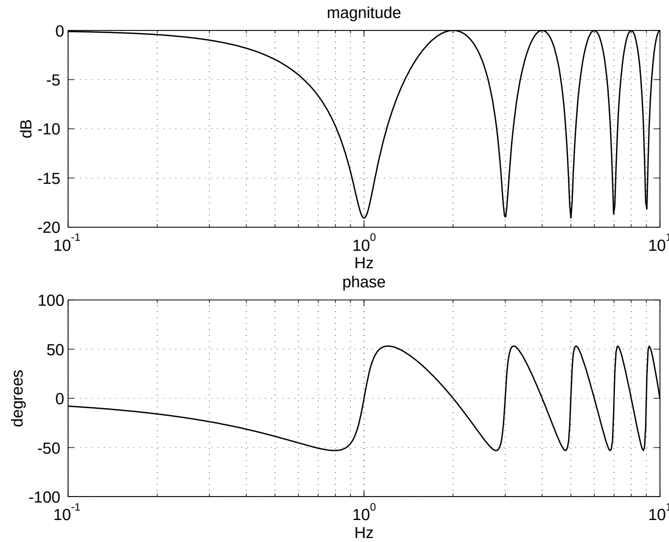



Fig. 4. Posicast frequency response for $\delta = 0.8, T_d = 1$

and the imaginary part is given by:

$$\text{Imaginary part } = \frac{2\pi}{T_d}(2n+1), \quad n = 0, 1, 2, \cdots \tag{3}$$

The frequency response of Posicast with $\delta = 0.8$ and $T_d = 1$ is shown in Fig. 4. The first pair of zeros cancels the dominant pair of poles in the lightly damped system.

## II. A Brief History of Posicast Research and Applications

The invention of Posicast control is due to Prof. Otto J. M. Smith (currently Professor Emeritus – University of California at Berkeley), who described the basic principles in the Sept. 1957 Proceedings of the IRE (Institute of Radio Engineers, forerunner of today's IEEE) [1]. Prof. Smith, best known for inventing the "Smith Predictor" for control of systems having time delay, also described Posicast in his 1958 textbook on feedback control [3].

A decade later, Gerald Cook, then a student at the Massachusetts Institute of Technology (MIT), published an article in the IEEE Transactions on Automatic Control, in which he described application of half-cycle Posicast to vibrating structures. Cook offered an excellent frequency domain interpretation for the Posicast element [2]. An example application of Posicast is the suppression of vibrations on a guided missile launcher [4]. Nearly twenty years later, Prof. Cook presented additional variations of Posicast, with application to the control of flexible structures [5].

The technique of preshaping command inputs to minimize structural vibrations was also being studied independently by mechanical engineers during this time. Dr. Neil C. Singer founded a company in 1989 to commercialize results of MIT research. The following year, he and Warren Seering described the underlying theory in terms of properly spaced impulse responses [6], and applied the method to suppress end

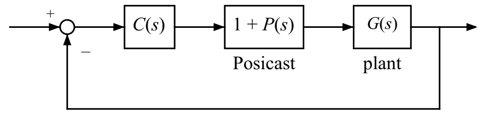



Fig. 5. Posicast within a feedback system [10]

point vibrations on Draper Lab's Remote Manipulator System simulator. Cook would later point out that their technique is theoretically equivalent to Posicast [7]. Sensitivity to modeling errors are reduced by Singer and Seering's methods, which can be interpreted as higher order forms of Posicast. The solution can be interpreted as placing multiple zeros in the vicinity of the lightly damped poles of the flexible system. A U.S. patent has also been separately issued for what appears to be a related concept called "staggered Posicast," in which multiple Posicast filters, each having distinct delay values, are chosen to attenuate resonances across a finite range [8]. In addition, a current search of the IEEE library via IEEEXplore reveals a large body of robotics research literature describing the concept and application of input preshaping.

From its conception and through the past 40-plus years, Posicast and related interpretations have the common characteristic of being feedforward control techniques. Higher order and multilevel variations can improve robustness, but classical Posicast generally suffers from sensitivity to modeling errors.

## III. REDISCOVERY AND NEW APPLICATIONS

Over the past five years, a method for designing feedback systems that incorporate Posicast has emerged, and is being applied to new engineering problems. Researchers have also implemented these techniques on a variety of technologies with encouraging results.

### A. Posicast in Feedback Control

The sensitivity problem can be reduced if Posicast compensation is applied within a feedback system rather than in the classical feedforward configuration [9], [10]. A block diagram explaining the control method is shown in Fig. 5. Whereas the classical applications placed Posicast before the lightly damped system, recent work suggests that Posicast be used within a feedback system. The proposed control method is a significant departure from classical Posicast. Note that the overall system characteristic polynomial using classical half-cycle Posicast is found by simply removing the dominant lightly damped poles of the plant $G(s)$. In the feedback approach, the closed loop characteristic polynomial is given by $1+C(s)[1+P(s)]G(s)$. The primary purpose of the Posicast function is to cancel undesirable plant poles, thus minimizing the effect of lightly damped poles in the closed loop response. Poles of the closed-loop system would be determined by the remaining open-loop poles and zeros.

A properly design compensator $C(s)$ reduces the effect of imperfect Posicast compensation. The design method for the hybrid system has two steps. First, the function $P(s)$ is designed for the lightly damped system $G(s)$. For half-cycle Posicast, two open loop step response parameters are required: the overshoot $\delta$ and the damped response period $T_d$. Next, the feedback controller $C(s)$ is designed based on the combined model $[1+P(s)]G(s)$. Classical frequency domain techniques can be used.

### B. A Design Example

A design example and several comparisons illustrate the effectiveness of Posicast within a feedback loop. The plant under consideration is modeled by

$$G_{(}s) = \frac{1}{(0.04s^2+0.08s+1)(0.01s^2+0.02s+1)} \tag{4}$$

which has two pairs of lightly damped poles at $s=-1\pm j5$ and $s=-1\pm j10$. All design work will be based on a second order approximation in which the higher frequency poles have been ignored.

From the dominant poles $s=-1\pm j5$, the two parameters of the Posicast element are computed:

$$\text{Overshoot } \delta = e^{-\pi/5}$$

$$\text{Period } T = \frac{2\pi}{5}$$

Design of the classical, feedforward half cycle Posicast controller is complete!

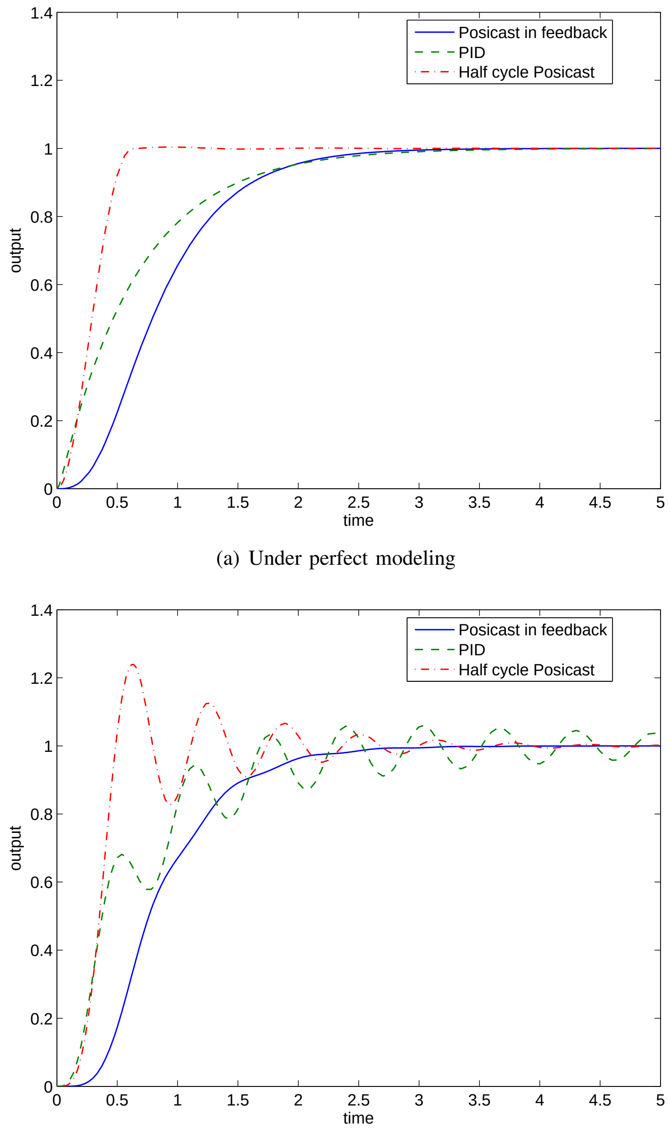
Posicast used in a feedback loop requires additional compensation to reduce sensitivity to mismatch. One candidate is simply an integrator with gain:

$$C(s) = \frac{K}{s} \tag{5}$$

The integrator increases the system Type, ensuring zero steady state error to constant reference commands. In addition, high frequency gain is reduced, thus minimizing the effect of high frequency unmodeled dynamics. The lagging phase characteristic will introduce overshoot in the response if the loop gain is too high. For this example, the gain value is chosen as $K=1.1$. Design of the Posicast based feedback controller is now complete; only one parameter was designed, since the two Posicast parameters are easily computed.

For purposes of comparison, the three gains of a proportional-integral-derivative (PID) type controller are designed to give performance comparable to the feedback controller with Posicast. The PID controller has two zeros, which are tuned to cancel the lower frequency poles of $G(s)$, in the same manner as the Posicast element. The gain of the PID controller is adjusted to yield the shortest settling time while minimizing overshoot. In addition, an additional pole with small time constant 0.02 is inserted to make the PID controller mathematically proper (number of zeros less than or equal to number of poles). The resulting PID controller transfer function is given by

$$C_{PID}(s) = 2.9\frac{s^2+2s+26}{s(s+50)} \tag{6}$$




(a) Under perfect modeling

(b) Under mismatched modeling

Fig. 6. Responses to Posicast in feedback, PID control, and feedforward Posicast.

Shown in Fig. 6(a) are the responses of the design model (without the high frequency poles) to the three controllers. The solid curve is the response to Posicast in a feedback loop. The dash-dot curve is the response to classical, feedforward Posicast. The dashed curve is the response to PID type feedback control. Classical Posicast yields the best response. The two feedback based approaches have increased the system order to guarantee zero steady state error, and the corresponding system response reflects the effect of increased lag.

When the three controllers are applied to the "true" system $G(s)$, the Posicast in feedback loop approach is the least affected. Fig. 6(b) shows the three responses when there is model mismatch. Classical, feedforward Posicast exhibits the highest sensitivity.

### C. A Note About Digital Control

The feedback controller with Posicast has been successfully demonstrated on digital signal processors. A key element is the time delay function described by $e^{-s(T_d/2)}$. Accurate implementation of the time delay function is affected by the digital controller sampling period. The controller sampling period $T$ is selected so that the following ratio is an integer number $N$:

$$N = (T_d/2) \div T \tag{7}$$

### D. Recent Developments

Application of Posicast in the feedback configuration was first demonstrated on dc-dc power converters. These systems can exhibit nonlinear behaviors, and the natural damping is strongly dependent on the load. PID type controllers implemented around specialized analog integrated circuits are the standard solution, although digital controllers being reported in the research literature [11]–[14].

The Posicast based feedback controller produces many of the beneficial closed loop effects of the PID type controller, such as good steady state performance and good damping of resonant behavior. Additional advantages that have been experimentally observed and verified include the following [15]:

- The control method produces a very good response that is predictable by the small signal, averaged, continuous time model of the dc-dc converter.
- The key element of the Posicast controller structure is especially easy to implement in discrete time hardware, and controller gains are easy to determine.
- The frequency response of the Posicast element inherently reduces high frequency noise, whereas PID control requires additional filtering to limit high frequency content.
- Experiments confirm that the gain margin of the Posicast compensated converter is as good, if not better than that of a PID compensated converter.

More advanced, multilevel Posicast has recently been applied with excellent results to other types of power converters. For example Li et al. design a three-level compensator for the low switching frequency current source rectifier [16], [17]. with precise resonance compensation and easy implementation.

Posicast has been incorporated into implementation and control of a dynamic voltage restorer for use in electric power distribution network control, where the goal is to compensate for voltage sags [18]. Loh et al. report effective control of the voltage restorer with perfect reference voltage tracking and effective damping of transient voltage oscillations at the instant of sag compensation.

Renewable energy sources such as wind-driven generators and solar power are being considered for connection to the power utility grids. Outputs from these sources vary much more than traditional energy generators, so new power electronic inverters are being developed. Many of these new inverters employ complex topologies that give rise to unusual resonances. Loh et al. describe the integration of Posicast into the control of a Z-source current-type inverter, using a digital signal processor [19]. Their work appears to suggest that the Posicast structure must be carefully chosen, and that a higher level structure may not always be superior to a simpler form.

## IV. Concluding Remarks

Invented 50 years ago, Posicast was originally designed as a feedforward compensator for lightly damped systems. The first reported applications were for mechanical structures. The technique is also closely related to input pre-shaping control, which has been widely studied and reported in the robotics research community. More recently, Posicast has been proposed for use within feedback loops, to take advantage of its superior damping qualities while also reducing Posicast's sensitivity to modeling error. Modern digital signal processors make it easy to accurately implement the time delay element that is at the heart of Posicast. Furthermore, the computing power of the digital signal processor has enabled engineers to apply Posicast based feedback control to new applications, such as power converters and inverters that interface to power grids. Classical application of Posicast is very simple, but the complex resonances of modern applications may make it more difficult to design Posicast. There remain opportunities to explore and apply intelligent design approaches with Posicast.

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