» 25 YEARS AGO

In this issue, "25 Years Ago" revisits the article "Anti-Windup, Bumpless, and Conditioned Transfer Techniques for PID Controllers," by Youbin Peng, Damir Vrancic, and Raymond Hanus, in *IEEE Control Systems Magazine*, vol. 16, no. 4, pp. 48–57, 1996. Below is an excerpt from the article.

In this article we give a simple and comprehensive review of anti-windup, bumpless and conditioned transfer techniques in the framework of the PID controller. We will show that the most suitable anti-windup strategy for usual applications is the conditioning technique, using the notion of the realizable reference. The exception is the case in which the input limitations are too restrictive. In this case, we propose the anti-windup method with a free parameter tuned to obtain a compromise between the incremental algorithm and the conditioning technique. We also introduce the new notion of conditioned transfer, and we will show it to be a more suitable solution than bumpless transfer. All the discussions are supported by simulations.

All industrial processes are submitted to constraints. For instance, a controller works in a limited range of 0–10 V or 0–20 mA, a valve cannot be opened more than 100% and less than 0%, a motor driven actuator has a limited speed, etc. Such constraints are usually referred to as plant input limitations. On the other hand, a commonly encountered control scheme is to switch from manual to automatic mode or between different controllers. Such mode switches are usually referred to as plant input substitutions.

As a result of limitations and substitutions, the real plant input is temporarily different from the controller output. When this happens, if the controller is initially designed to operate in a linear range, the closed-loop performance will significantly deteriorate with respect to the expected linear performance. This performance deterioration is referred to as windup. Besides windup, in the case of substitution, the difference between the outputs of different controllers results in a big jump in the plant input and a poor tracking performance. This mode switching,

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which results in such phenomena, is referred to as bump transfer.

A rational way to handle the problem of windup is to take into account, at the stage of control design, the input limitations. However, this approach is very involved and the resulting control law is very complicated. The nonlinearities of the actuator are not always known apriori. A more common approach in practice is to add an extra feedback compensation at the stage of control implementation. As this compensation aims to diminish the effect of windup, it is referred to as anti-windup (AW).

In the case of mode switching, the method that aims to minimize the jump at the plant input is referred to as the bumpless transfer (BT). Yet to minimize the jump is not always preferable, since this may cause a relatively poor tracking performance. Thus we refer to the method that will not only reduce the jump at the plant input but also keep a good tracking performance as conditioned transfer (CT). This new notion will be shown to be very useful later in this article. An anti-windup strategy is usually implemented as a bumpless transfer technique. Indeed, an anti-windup method will usually diminish the jump at the plant input during mode switching. However, it should be pointed out that anti-windup does not necessarily imply bumpless transfer.

The topic of anti-windup and bumpless transfer has been studied over a long period of time by many authors, and the most popular techniques are described in [2], [4], [7], [11], [16]. However, although the concept of anti-windup and bumpless transfer is introduced in almost every basic control textbook, it is not clearly illustrated and is sometimes misinterpreted. For instance, many authors think that anti-windup is aimed at reducing the output overshoot in its step response, or that anti-windup is a synonym for bumpless transfer, or that the best transfer transition is to eliminate the jump at the plant input. These thoughts need to be corrected. Recently, Kothare et al. [10] have presented a general framework for anti-windup design that is a very useful guide for theoretical researchers. Yet a practical control engineer may still look for a simpler tutorial.

Conditioned transfer assures good tracking performance at the cost of a possible small jump at the plant input during mode switching.

Therefore, the objectives of the present article are as follows. First, we would like to illustrate through simulations the phenomenon of windup and bump transfer. We will limit ourselves to the framework of the PID controller, since it is the most common industrial controller and it frequently experiences windup and bump transfer problems. Then we will review the majority of existing anti-windup methods, illustrate the improved results, and compare those methods by using the notion of the realizable reference. Subsequently, we will investigate the case of mode switching and introduce the new notion of conditioned transfer. It will be shown that conditioned transfer is a more suitable solution than bumpless transfer. Finally, we will include some discussions of practical issues.

CONCLUSIONS

We have illustrated, through simulations for PID controllers, the phenomenon of windup and bump transfer, and the improved results obtained using the techniques of anti-windup, bumpless transfer, and conditioned transfer. The majority of existing anti-windup, bumpless, and conditioned transfer techniques have been reviewed in the framework of the PID controller. Using the so-called realizable reference, we have shown that the conditioning technique is the most suitable anti-windup method for usual applications. The exception is the case in which the input limitations are so restrictive that the system output might become oscillatory. In such a case, the controller parameters could be changed in the design stage to damp the oscillations, or an anti-windup method with a tuning parameter Ka (tuned to obtain a compromise between the incremental algorithm and the conditioning technique) could be used.

Two types of transfers in the case of mode switching are described. Although bumpless transfer is a well-known concept, its resulting tracking performance might be degraded. The new notion of conditioned transfer is thus introduced for the first time in this article. Conditioned transfer assures good tracking performance at the cost of a possible small jump at the plant input during mode switching.

Utilizing many other simulations [14], we have tested the above conclusions and found them to be always valid if the closed-loop system demonstrates satisfactory performance in the unlimited case, no matter which process and controller are used.

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