SYS 402 REVIEW

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PID Controller Tuning Using Bode's Integrals.

PID controllers, just like it was seen in the labs of SYS 402, have a significant role in various industrial plants and in general, in control theory. The design and fine tuning of that kind of controllers, always have been a challenge for scientists and engineers. Over the years, various methods have been proposed to solve this problem, but due to the complexity of the non linear equations that occur, there is no analytical solution that can meet the specifications of a real "plant". In 1984 Astrom and Hagglund, proposed an automatic tuning method based on a simple relay feedback test, which gives the critical frequency and critical gain of the system. Using the Nyquist curve, they identified other points of the frequency response of the plant, and then using the heuristic method that Ziegler-Nichols proposed in 1942 for autotuning of the PID controller, moved this point to another position in the complex plane. Although it seems simple, for this particular method to work, the derivatives of the plant's transfer function, with respect to frequency, must be known in advance, which they are not.

To solve that problem, the writers used the Bode integrals to approximate the derivatives of the plant transfer function. Two integrals were used, the first one shows the relationship between the phase of the system at each frequency, as a function of its amplitude. The second one, shows how the amplitude of the system at each frequency is related to the derivative of the phase and the static gain of the system. With knowledge of the derivatives, one can use them in the modified ZN method to adjust the slope of the Nyquist curve at the crossover frequency.

So far, so good, but the question remains, does it work? After many simulations on some typical industrial models, the absolute normalized error of the estimates, was in an acceptable range, near 0.01 - 0.1, for several first order models. For systems that oscillate, in general it works, but not for every frequency, while for nonminimum-phase systems the Bode's integrals have no longer meaning.

As mentioned before, on one hand, one main challenge in PID technology is the tuning part, but on the other hand, the design itself of the controller is quite challenging. After obtaining the information about the amplitude, phase, crossover frequency and static gain, the new goal is to improve the PID performance, by adjusting the phase margin and the slope of the

Nyquist curve at the crossover frequency. The biggest advantage using the above method, the Bode integrals alongside the modified ZN, is that no model of the system is needed, and the equations that describe the improved controllers are universal. Comparing the proposed method, with just the modified ZN, one can see that the first one show a significant improvement of the closed loop performance. While the overshoot remains the same, the settling time is nearly 50% smaller than the ZN method. Last, but not least, investigating the Nyquist diagrams, the proposed method controllers, modify the slope of the Nyquist curve and they improve the margin of the system.

So far, it was assumed, that the amplitude, phase at the crossover frequency are known or easily to be measured. If, however, the crossover frequency is different from the measured one, an analytic solution is not available. In other words, improvement of the performance of the closed loop system by increasing the crossover frequency is not possible. For a situation that was described above, the method that the authors suggested, includes a combination of a relay test with gain adjustment. To be more accurate, the method gets split in to two iterative procedures. One only for phase margin adjustments, and the other, for phase and gain margin adjustment. The first case is preferable for the majority of industrial plants and uses only the information on one frequency point of the plant, making it quite fast and simple. The second case, is a bit more complex, and it is the only choice, when it comes to high order systems. For such systems, the phase and gain margins, get tuned at the same time, meaning that two relay tests need to be done, one for phase margin and one for gain margin respectively. Comparing the second method with "pure" ZN, and particularly, a comparison of the closed loop performance between a controller using the second method and ZN, show that the proposed method achieves smaller settling time with a really small overshoot.

In a real "world" experiment, the above results were confirmed, while at the same time, it was proved that this new method is also fast enough to be used for autotuning and readjusting the controller parameters of systems, with slow changes in operation points(converges in a few iterations).

In conclusion, PID controllers using Bode's Integrals alongside the modified ZN, can be a method for creating a controller with universal equations, and the only knowledge to design them will be the amplitude, and the phase in the crossover frequency, no model of the plant. Furthermore, when it comes in the tuning part, the so call improved method works really good for typical industrial models. Finally, the iterative methods that were introduced, converge in only a few iterations to the minimum, and can definitely be used for autotuning simple and more complex (meaning high order) systems.

References

[1] Karimi,A., Garcia,D., Longchamp,R., et al. (2003). *PID Controller Tuning Using Bode's Integrals*. IEEE TRANSACTIONS ON CONTROL SYSTEMS TECHNOLOGY, VOL. 11, NO. 6, 812-821.