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1 Problem Formulation

In an attempt to surpass the inherent design limitations of linear (control) systems, the use of nonlinear control strategies has been increasingly considered over the past decades. A recent example of such an applied nonlinear control strategy is the Hybrid Integrator-Gain System (HIGS). Compared to other strategies, the HIGS posesses the benefits of generating continuous output signals with input-equivalent signs which, in turn, give rise to reduced phase lag as observed through describing function analysis. Dedicated experiments on an industrial wafer scanner have illustrated the performance improving potential that HIGS-based control can offer, see e.g. [1]. Unfortunately, such improvements come at the expense of increased complexity and decreased transparency during the controller design process.

2 Design Procedure

In order to systematically design HIGS-based controllers, a method is proposed that a) allows for an intuitive tuning of parameters through describing function-based loopshaping, and b) provides a rigorous a posteriori closed-loop stability check.

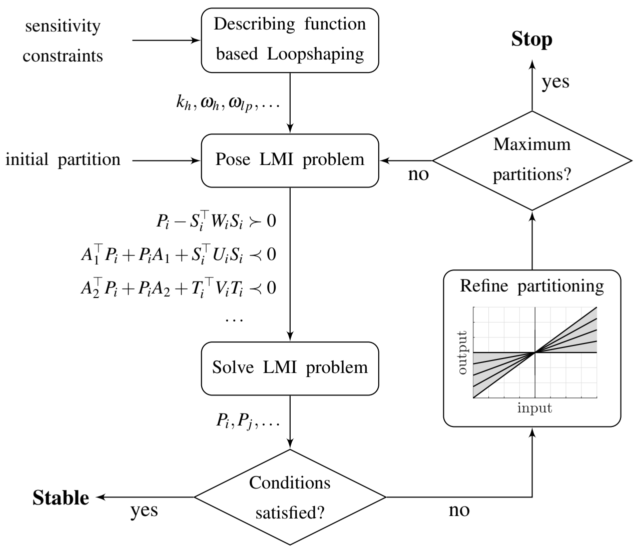

Figure 1: Design procedure for HIGS-based control systems.

The latter involves the iterative search for admissible piecewise quadratic Lyapunov functions by 1) partitioning of the HIGS' input-output space into smaller regions, and 2) solving a set of corresponding Linear Matrix Inequalities (LMIs) numerically. A refinement of the partitioning can significantly reduce conservatism in the analysis. The design procedure is summarized in Figure 1.

3 Illustrative Example

To demonstrate the effectiveness of the proposed design procedure, several HIGS-based feedback controllers, consisting of the HIGS in series with a linear filter, are designed for a fourth-order motion system. The frequency response functions $L(j\omega)$ resulting from describing function based loopshaping, are shown in a Nyquist-like plot in Figure 2. Accordingly, the results from the iterative LMI-check are shown in Table 1.

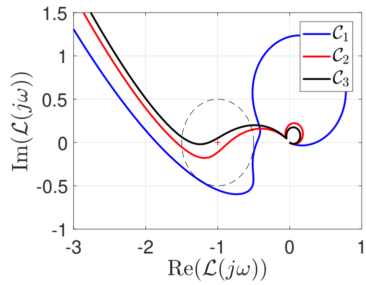

Figure 2: Nyquist-like plots of the controller designs.

Table 1: Results from an iterative LMI check.

	C_1	C_2	C_3
LMIs	Feasible	Feasible	Infeasible
Minimal partitions	2	30	-

By comparing these results with the step response of the simulated closed-loop systems shown in Figure 3, it appears that the describing function provides a surprisingly good prediction for the closed-loop system behaviour.

4 Conclusion

Describing function based loopshaping, combined with a rigorous LMI-based stability check provides a useful approach for HIGS-based controller design.

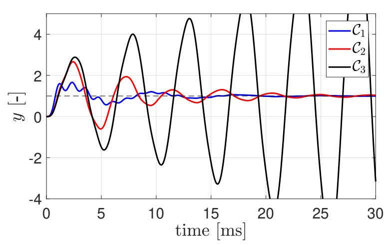

Figure 3: Simulated closed-loop step response.

References

[1] S. van den Eijnden, Y. Knops, and M. Heertjes, A hybrid integrator-gain based low-pass filter for nonlinear motion control, *Proc. of the CCTA*, Copenhagen, Denmark, pp. 1108-1113, 2018.