Nonlinear problems in control of manufacturing systems

Leonov G.A., Adan I., Andrievsky B.R., Kuznetsov N.V., Pogromsky A.Yu., Starkov K.

Abstract: Nowadays, production control problems have been widely studied and a lot of valuable approaches are implemented. This talk addresses the problem of tracking the uncertain demand in case of uncertain production speeds. The uncertainties are described by deterministic inequalities and the performance is analyzed in the from of worst-case scenarios.

First, simple mathematical models are introduced and the control problem is formulated. In continuous-time the cumulative output of a manufacturing machine is the integral of the production speed. At the same time, the production speed is bounded from below and above, and hence, the manufacturing process can be modeled as an integrator with saturated input. Since the cumulative demand (the reference signal to track) is a growing function of time, it is natural to consider control policies that involve integration of the mismatch between the current output and current demand. In the simplest setting it results in models similar to a double integrator closed by saturated linear feedback with an extra input modeling disturbances of different nature. This model is analyzed and particular attention is paid to the integrator windup phenomenon: lack of global stability of the system solutions that correspond to the same input signal. For example, for a given periodic disturbance the system can have different periodic solutions, that, in turn, makes the performance analysis virtually impossible. As a systematic design procedure to prevent the windup phenomenon we present observer based techniques with full and reduced-order observers.

The next part of the talk deals with a similar control problem in discrete-time under the surplus-based policy: each machine in the production network tracks the demand trying to keep the downstream buffer at some specified safe level. The performance of manufacturing networks with different topologies is analyzed via the second Lyapunov method, while the disturbances are modeled as deterministic inequalities. The nature of the approach leads to performance analysis in the form of worst case scenarios and allows to find a trade-off between the inventory in the system and the demand tracking accuracy.

The third part of the talk illustrates how to make the theoretical findings operational with the experimental setup called Liquitrol. The experimental setup consists of a number of water tanks and pumps that can be interconnected via flexible piping. Each tank represents a buffer with the water playing a role of products. Each pump emulates a manufacturing machine and via piping it is possible to emulate different topologies of the manufacturing network. Due to its flexibility and mobility the setup allows not only to verify theoretical results via experiments, but also can be used in educational process to illustrate different phenomena in tandem and re-entrant manufacturing networks.