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The Tracking Ratio Station

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ABSTRACT

In ratio control, the control objective is to keep the ratio between two signals, normally flow measurements, at a desired value in spite of variations in setpoints and load disturbances, and possible control signal saturations. This paper presents a new ratio control scheme, the Tracking Ratio Station, that manages to handle all these situations. It is also able to keep the ratio when one of the controllers takes a local setpoint or is switched to manual control. The Tracking Ratio Station determines the setpoints of the two flow loops so that the one with the largest control error follows the external setpoint, whereas the one with the smallest control error follows the process output of the opposite control loop. The paper illustrates the properties of the Tracking Ratio Station in terms of both simulations and industrial field tests.

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1. Introduction

In ratio control, the control objective is to keep the ratio between two variables, often flows, at a certain ratio a. In boilers and furnaces, e.g., it is desired to control the ratio between the fuel and the air supply to obtain a combustion that is as efficient as possible. Blending of chemicals is another example where it is desired to keep the ratio between different flows at a certain ratio. In in-line blending systems, when there are no downstream mixing tanks, this is of special importance. If the right composition is not maintained, quality problems may occur.

Ratio control problems may also show up in mechanical constructions where it is desired to synchronize velocities, e.g., of conveyor belts. In this paper, it is assumed that the process outputs are flows, but the results are applicable to velocity problems as well.

Ratio control is a very common control problem. In process control plants, the number of controllers treating ratio control problems is estimated to be between 10% and 20% of the total number of controllers, which means that there are several hundreds of them in a larger process industry. Therefore, an improvement of the structures used for ratio control may have a great impact, see Hägglund (2013).

Ratio control is a TITO (two input two output) control problem. There are two setpoints, the desired flow, either the total flow or the flow of one of the components, and the desired ratio a between the flows. There are two measurement signals, the two flows, and there are two control signals, the inputs to the two valves or pumps that control the flows.

Ratio control problems can be divided into two categories depending on which of the two setpoints that is considered most important to track. Sometimes there is a master flow that one cannot or does not want to change to control the ratio. In this case, keeping the two flows close to ratio a is a secondary problem. The other category is those cases where tracking ratio a is the most important task, and keeping the flow close to the setpoint is less important. This paper treats problems belonging to this second category.

An efficient ratio control configuration should be able to take care of setpoint variations, load disturbances, and control signal saturations. The flow setpoint is normally varying to follow demands on combustion or production rate. The desired ratio is often constant in blending systems, but in combustion it is often adjusted based on O_2 measurements in the exhaust. There are various reasons for load variations, e.g., pressure variations in the tubes, and the control signals are often reaching their limits when the control is aggressive and the actuators are not oversized.

In those applications where Model Predictive Control (MPC) is used, the problem may be solved by the MPC. However, most ratio control problems are solved in the regulatory level, and there is no reason to introduce MPC just for the purpose of solving the ratio control problem. This paper treats the problem of ratio control in the regulatory level of the instrumentation.

Most ratio control approaches manage to keep the ratio between the flows in steady state, but so far there has not been any approach that manages to track the ratio during all possible transients caused by setpoint changes, load disturbances and control signal limitations. This paper describes the Tracking Ratio Station (TRS) that manages to take all these disturbances into account. It is also able to keep the ratio when

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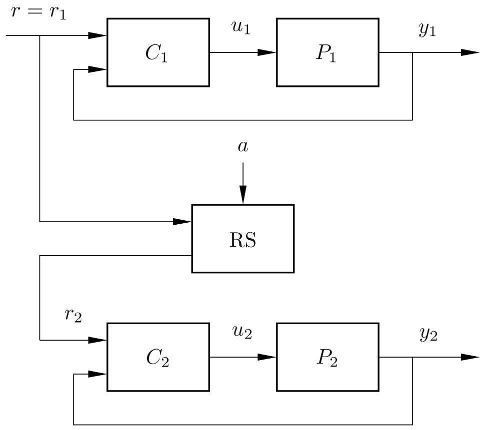

Fig. 1. Ratio control using a parallel Ratio Station (RS) applied to setpoint $r_1(t)$.

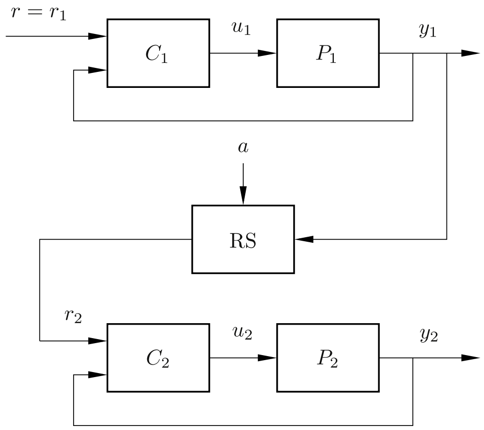

Fig. 2. Ratio control using a series Ratio Station (RS) applied to flow $y_1(t)$.

one of the controllers takes a local setpoint or is switched to manual control.

In the next section, previous approaches to ratio control are described and compared. In Section 3, the TRS scheme is described. Simulation experiments verifying the ability to track ratio a are provided in Section 4. Section 5 presents industrial field tests performed at a paper mill. Section 6, finally, gives a summary and conclusions.

2. Ratio control strategies

This section presents previous approaches to ratio control schemes, and the advantages and disadvantages of these schemes with respect to setpoint changes, load disturbances, control signal saturations, and controllers switched to local setpoint or manual control are discussed.

The control problem is to synchronize two flow control loops, with process models $P_1(s)$ and $P_2(s)$, controllers $C_1(s)$ and $C_2(s)$, flow measurement signals $y_1(t)$ and $y_2(t)$, control signals $u_1(t)$ and $u_2(t)$, and flow setpoints $r_1(t)$ and $r_2(t)$.

The two flows should be controlled so that a desired ratio a between them is retained, i.e.,

$$\frac{y_2(t)}{y_1(t)} = a$$

Throughout the paper, it is assumed that the flow demand $r(t)$ is provided as the setpoint to the first flow, i.e., $r_1(t) = r(t)$. This is not always the case, the external flow demand is, e.g., quite often the total flow. Modification of the results in this paper to this case is, however, trivial. It means that $r_1(t)$ is given as $r_1(t) = r(t)/(1 + a)$ instead. It will also be assumed that a is constant, although the results are not restricted to this assumption.

2.1. The parallel Ratio Station

Ratio control is traditionally obtained using simple Ratio Stations. Ratio Stations are basically multipliers, where the output is derived as an input signal multiplied with the desired ratio a. See Shinskey (1981, 1996), and Seborg, Edgar, and Mellichamp (1989). A common, and the perhaps most intuitive, ratio control scheme is the parallel Ratio Station, described in Fig. 1. Here, setpoint $r_2(t)$ is determined as

$$r_2(t) = a r_1(t) \tag{1}$$

If controllers C_1 and C_2 have integral action, and provided that the control signals are not saturated, the control objective is obtained in steady state, i.e., $y_1(t) = r(t)$ and $y_2(t)/y_1(t) = a$.

However, the parallel Ratio Station is an open-loop approach in the sense that there is no attempt to keep the ratio during load disturbance responses, at control signal saturations, or when one of the controllers is switched to local setpoint or manual control.

The ratio will not be kept during setpoint variations either, unless the two loops have the same dynamics. It is sometimes suggested to try to obtain the same dynamics in the two loops by detuning the controller in the fastest loop. This is, however, not a good approach if there are load disturbances present in this loop. A better approach is to feed the setpoint of the fastest loop through a low-pass filter, and in this way try to obtain the same dynamics between the setpoints and the process outputs of the two loops.

2.2. The series Ratio Station

Using the parallel Ratio Station, the two flow loops are treated in the same way. In the series Ratio Station, the first loop is a master loop, and the second one is a slave loop, and the input to the ratio station is the process output of the master loop instead of the setpoint. This is illustrated in Fig. 2, where setpoint $r_2(t)$ is determined as

$$r_2(t) = a y_1(t) \tag{2}$$

i.e., by multiplying flow $y_1(t)$ with the desired ratio a.

The advantage of the series implementation of the Ratio Station compared to the parallel one is that load disturbances and control signal saturations appearing in the master loop are compensated for in the slave loop, leading to a better tracking of the ratio in these cases. The ratio will also be retained when the master controller is switched to local setpoint or manual control. Load disturbances, saturations, and mode switches in the slave loop are still not treated.

A drawback of the series implementation is that the ratio will not be kept during setpoint variations, since the second flow $y_2(t)$ will always be delayed compared to the desired flow $a y_1(t)$. The length of this delay is determined by the dynamics in the slave loop. This is a severe drawback, since flow demand $r(t)$ is often varying in ratio control applications. Another drawback is that measurement noise in the master loop is introduced in the slave loop via the setpoint $r_2(t)$. This may cause wear on the actuators. The problem can be reduced by feeding the setpoint to the slave controller through a low-pass filter.

When setpoint $r(t)$ is increasing, the delay causes an under-supply of the media corresponding to flow $y_2(t)$, and conversely when $r(t)$ is decreasing there is an excess of the media corresponding to flow $y_2(t)$. There are cases when it is important to never get any under-supply of one of the two media. In combustion, e.g., it is often desired to never have any under-supply of air, since this means that the fuel is not completely burned. This situation can be avoided by combining the series Ratio Station with some MAX/MIN selectors that switches the master and slave roles of the two loops depending on whether the combustion is increasing or decreasing. See Åström and Hägglund (2006).

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