Control Engineering Practice 42 (2015) 28–40

Contents lists available at ScienceDirect

Control Engineering Practice

journal homepage: www.elsevier.com/locate/conengprac

Production scheduling of parallel machines with model predictive control

Andrea Cataldo*, Andrea Perizzato, Riccardo Scattolini

Dipartimento di Elettronica, Informazione e Bioingegneria, Politecnico di Milano, Piazza Leonardo da Vinci, 32, 20133 Milan, Italy

ARTICLE INFO

Article history:
Received 27 August 2014
Accepted 12 May 2015
Available online 8 June 2015

Keywords:
Model predictive control
Receding horizon control
Model based control for manufacturing plants
Propositional calculus for manufacturing processes
Energy efficiency for manufacturing processes

ABSTRACT

This paper considers the problem of optimizing on-line the production scheduling of a multiple-line production plant composed of parallel equivalent machines which can operate at different speeds corresponding to different energy demands. The transportation lines may differ in length and the energy required to move the part to be processed along them is suitably considered in the computation of the overall energy consumption. The optimal control actions are recursively computed with Model Predictive Control aiming to limit the total energy consumption and maximize the overall production. Simulation results are reported to witness the potentialities of the approach in different scenarios.
© 2015 Elsevier Ltd. All rights reserved.

1. Introduction

The energy efficiency of manufacturing production systems is becoming a topic of paramount interest for many reasons, such as the need to minimize the energy consumption of industrial plants, to resize the factory energy supply infrastructures, and to limit the CO_2 emissions, see e.g. European Commission (2009), Organization for Economic Cooperation and Developoment (2004), Seliger (2007), and ICF International (2007). Different levels of manufacturing efficiency have been considered in the literature (Fysikopoulos, Pastras, Alexopoulos, & Chryssolouris, 2014): (i) the process level, which concerns the energy interaction related to the physical machining operations; (ii) the machine level, which considers both processing and auxiliary operations; (iii) the production line level, which refers to a group of different machines and, finally, (iv) the factory level, which concerns the high-level managing of different production lines, possibly interacting and sharing common appliances. In general, improving the efficiency at the lower levels (machine and process) is a complex task because it may result in worsening quality and costs or it may require the deployment of new and more advanced processing techniques. By contrast, energy efficiency at the production or factory level can be improved by designing suitable production scheduling and planning algorithms. This level of optimization is usually preferred because it is less invasive and does not effect quality and costs. For this reason, the development of optimization algorithms for the solution of scheduling problems, such as job shop, flow shop, and flexible flow shop, has been the subject of a huge scientific effort, see e.g. Pinedo (2008) and the references reported there. Recent contributions explicitly dealing with the energy efficient scheduling of production systems are reported in Angel, Bampis, and Kacem (2012), Haït and Artigues (2009), Fang, Uhan, Zhao, and Sutherland (2011), Bruzzone, Anghinolfi, Paolucci, and Tonelli (2012), and Dai, Tang, Giret, Salido, and Li (2013).

This paper considers the problem of optimizing on-line the production scheduling and buffer management of a multiple-line production plant composed by L machines M_i, $i = 1, \dots, L$, which can operate at different speeds corresponding to different energy demands. The path from a common source node, where the part to be processed is assumed to be always available, to each machine may differ in the number of buffer nodes, and the energy required to move the part along these transportation lines must be suitably considered in the computation of the overall energy consumption. Therefore, the control problem consists of computing, at each sampling instant, the sequence of commands to be applied to the transportation lines and the processing speed of the machines in order to optimize the throughput of the system and to limit the overall energy consumption. This problem, which shares some similarities with the classical flexible flow shop problem, has been motivated by the optimal management of the de-manufacturing plant described in Colledani, Copani, and Tolio (2014) and Copani et al. (2012). Specifically, this plant is made by a number of machines and a multi-path transportation line, part of which is

* Corresponding author. Tel.: +390223994034.
E-mail addresses: andrea.cataldo@polimi.it (A. Cataldo), andrea.perizzato@gmail.com (A. Perizzato), riccardo.scattolini@polimi.it (R. Scattolini).

http://dx.doi.org/10.1016/j.conengprac.2015.05.007
0967-0661/© 2015 Elsevier Ltd. All rights reserved.

made by two parallel independent transport lines which start from the same source node and feed two independent machines. The design of the optimal pallet routing has been already considered in Cataldo and Scattolini (2014a, 2014b), where however the target machine of each pallet has been assumed to be a priori given.

The optimal scheduling of parallel machines, which must guarantee the completion of a given number of tasks by assigning them to different machines, has been considered in many papers, see e.g. the review (Senthilkumar & Narayanan, 2010) and the references therein. This problem is known to be very complex, see Weng, Lu, and Ren (2001), and therefore the proposed solutions are mainly based on the development of heuristics, see e.g. Kim, Na, and Chen (2003), Rabadi, Moraga, and Al-Salem (2008), and Jansen and Porkolab (2001). On the contrary, the approach here proposed relies on Model Predictive Control, or MPC, see e.g. Camacho and Bordons Alba (2004), a technique widely popular in the process industry, such as chemical, petrochemical, pulp and paper, but still in its infancy in the field of discrete manufacturing, save for the notable exceptions of Vargas-Villamir and Rivera (2001), Vargas-Villamir and Rivera (2000), Alessandri, Gaggero, and Tonelli (2011), Braun, Rivera, Flores, Carlyle, and Kempf (2003), Ydstie (2004), Ferrio and Wassick (2008), Wang and Rivera (2008), where problems related to the management of supply chains have been studied. MPC is based on the simple idea of transforming the control problem into an optimization one, where different goals and constraints on the process variables can be included. Specifically, in the problem here considered, MPC recursively computes the optimal sequence of buffer commands and machines' processing times over a given prediction horizon by minimizing the overall energy consumption and maximizing the future production. Then, only the first value of the optimal sequence is applied and the overall optimization procedure is repeated at the next time instant. Optimization is performed under suitable constraints on the production, on the electric power involved, and under the physical constraints imposed by the system. These constraints are described by logical statements, which in turn are transformed into algebraic relations among boolean variables, see Bemporad and Morari (1999). Moreover, the machines are represented by finite state machine models, so that the overall system to be optimized is described by a Mixed Logical Dynamic (MLD) model, see again Bemporad and Morari (1999), a representation which combines discrete time dynamics with logical (boolean) decision variables. Thanks to the use of MLD models, the resulting optimization problem belongs to the class of Mixed Integer Linear Programming (MILP) problems, for which fast solvers are available.

The paper is organized as follows. In Section 2 the problem is stated, the models of the components, i.e. machines and buffer zones, are developed, and the overall MLD model is derived. In Section 3 the optimization problem is formulated and its main characteristics are examined. Section 4 is devoted to present and critically analyze some simulation results where different scenarios are considered. Finally, in Section 5 some conclusions and hints for future developments close the paper.

2. Problem formulation

The generic structure of the production system considered in this paper is sketched in Fig. 1: it consists of L parallel production lines, each one with p_i, $i=1,\dots,L$ buffer nodes ended by a machine M_i (Fig. 2). The machines $M_1,\dots,M_L$ are assumed to have a controllable and variable duration processing time related to the required energy to perform the machining operations. This means that it is possible to choose whether a machine must process the next part at full or slow speed with consequent high or low energy demand. The binary variable $u_{i,j}$, $i=1,\dots,L, j=1,\dots,p_i$ represents the trigger which moves the part from node $N_{i,j-1}$ to $N_{i,j}$. Specifically, $u_{i,j}=0$ if the part is not moved from $N_{i,j-1}$ to $N_{i,j}$ or if node $N_{i,j-1}$ is empty, while $u_{i,j}=1$ if the part is moved from $N_{i,j-1}$ to $N_{i,j}$.

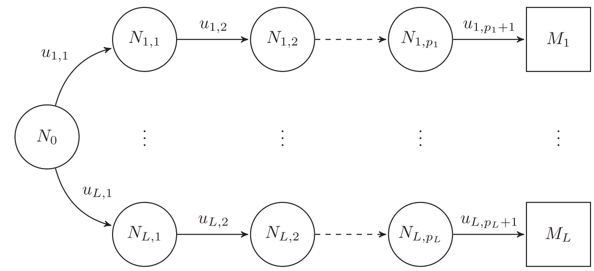

Fig. 1. Production system.

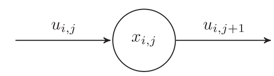

Fig. 2. Node model.

The control problem consists in moving the parts from the root node N_0 to the machines $M_1,\dots,M_L$ and in deciding the processing time of each machine, while ensuring that constraints on maximum power and minimum production are fulfilled.

Assumption 1. The root node N_0 always contains a part, i.e. there is always a part ready to be processed by the system.

2.1. Node model

Let $x_{i,j}$ be a logical state related to node $N_{i,j}$ and let $x_{i,j}=1$ when $N_{i,j}$ contains a part and $x_{i,j}=0$ otherwise. The variable $u_{i,j}$ is logical as well, and $u_{i,j}=1$ means that the part will be moved from $N_{i,j-1}$ to $N_{i,j}$.

Letting k be the discrete time index, the dynamics of the logic state is given by

$$x_{i,j}(k+1)=x_{i,j}(k)+u_{i,j}(k)-u_{i,j+1}(k) \qquad (1)$$

In order to simplify the notation, from now on we will drop the time index k when not required for clarity of presentation. Moreover, the superscript $^+$ will denote the variable at the next time instance, so that, given a generic variable $\varphi(k)$, the symbol φ will correspond to $\varphi(k)$ and φ^+ to $\varphi(k+1)$. According to this notation, (1) can be written as

$$x_{i,j}^+=x_{i,j}+u_{i,j}-u_{i,j+1} \qquad (2)$$

The inputs $u_{i,j}$ must be suitably constrained in order to prevent the states taking values different from zero and one, and to avoid unrealistic configurations, such as moving a part out of an empty node. In particular, it is possible to move a part into $N_{i,j}$ if and only if all the following conditions are fulfilled:

1. The node $N_{i,j-1}$ contains a part .
2. The node $N_{i,j}$ is empty or it contains a part which is moved to $N_{i,j+1}$ at the same time instant.

These conditions can be rewritten using logical operators as

$$\neg x_{i,j-1} \wedge (\neg x_{i,j} \vee (x_{i,j} \wedge u_{i,j+1})) \qquad (3)$$

which, according to the propositional calculus rules (Bemporad & Morari, 1999; Lucas, Mitra, & Moody, 1992; McKinnon & Williams, 1989; Raman & Grossmann, 1991; Williams, 2013), is equivalent to

$$\begin{aligned} &u_{i,j} \le x_{i,j-1} \\ &u_{i,j} \le 1-x_{i,j}+u_{i,j+1} \end{aligned} \qquad (4)$$

Download English Version:

https://daneshyari.com/en/article/698997

Download Persian Version:

https://daneshyari.com/article/698997

Daneshyari.com