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Second-order consensus predictive control for 360*MN* extrusion machine ☆

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ABSTRACT

A new consensus predictive control protocol is proposed in this paper. It significantly speeds up the convergence rate comparing to traditional consensus mechanism and has been proved working well in simulation platform. A mathematical model is built by simplifying the hydraulic cylinders to single-DOF agents distributed evenly around 360*MN* extrusion machine's main table. With this model, a theoretical analysis of the mechanism is given and the validity of the consensus predictive control protocol for strong coupling multi-agent system on ADAMS–EASY5 simulation platform is illustrated. The machine's main table balance problem is well solved and the convergence rate is increased. These results are meaningful for increasing productivity.

1. Introduction

Built in 2009, Baotou of China, 360*MN* vertical black metal extrusion machine has greatly enhanced the productivity of high quality thick-walled seamless tubes, which brings a significant influence to the thick-walled tube industry (Li, Li, Peng, & Zhao, 2012). This paper focuses on the control problem of machine's main table. Six hydraulic cylinders drive the main table upward during the extrusion process. They are symmetrically installed around main table's plane and codetermine the attitude of the main table. Considering the strong coupling, the control strategy must be implemented simultaneously to cylinders, which is a challenging issue. These uncertain disturbances and resistances caused by temperature asymmetry of the ingot, metal turbulence and inconformity among cylinders make this control problem even harder because they may bring an unbalance torque which can lead the main table's tilt and extrusion failure. It is necessary to design an efficient close-loop control protocol to keep the main table on balance during the movement. To analyze and validate the control algorithms, a mechanical hydraulic simulation platform for 360*MN* extrusion machine is used, based on physical model with high precision by ADAMS and EASY5 software, which makes it close to the actual case (Li et al., 2012).

Consensus control mechanism was introduced to 360*MN* extrusion machine control strategies (Wang et al., 2013) because consensus control is commonly used for cooperated control and this issue has some similarities to the multi-vehicle cooperated control problem. Consensus control mechanism can solve the problem described above.

Recently, some papers showed that model predictive control mechanism and consensus control mechanism can be both used into a control algorithm, and called this method consensus predictive control, which predicts the future states of agents based on their current and past several steps of states, and also improves the performance of control system. For example, the feasible range of sampling period was remarkably expanded and the convergence speed was significantly improved, compared with routine consensus control (Trecate, Galbusera, Marciandi, & Scattolini, 2009; Zhang, Chen, & Stan, 2011; Zhang, Chen, Stan, Zhou, & Maciejowski, 2008; Zhang, Chen, & Zhou, 2009; Zhang, Chen, Zhou, & Stan, 2008).

Predictive intelligence mechanism has been widely found in the behavior of natural bio-groups. Experiments have found evidences for the existence of predictive mechanisms in bee swarm movement (Melcher, 2007; Montague, Sayan, Person, & Sejnowski, 1995; Woods, 1959). Actually, linear model predictive control algorithm has been widely studied for more than four generations and increasingly found in a wide variety of application areas (Qin & Badgwell, 2003). Some predictive control applications are similar to 360*MN* extrusion machine discussed in the paper, for instance, the application of food extrusion process (Wang, Smith, & Chessari, 2008; Wang & Tan, 2000) and the decentralized control for multi-evaporator air conditioning system (Elliott & Rasmussen, 2013).

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The objective of present work is to improve the consensus control algorithm by combining predictive mechanism to consensus control. In this paper, the conclusion has been obtained that the convergence speed of this new control protocol could be significantly improved by two ways: (1) comparing the consensus predictive control protocol's spectral radius with consensus control protocol's mathematically, (2) simulating those two protocol on co-simulation platform. It is meaningful because faster convergence speed could promote the product quality.

This paper is organized as follows. In Section 2, the state equation of 360*MN* extrusion machine is introduced. Control protocol with consensus predictive mechanism is designed in Section 3. The algorithm analysis is in Section 4. Section 5 gives some mathematical simulation cases comparing the new protocol with consensus control. In Section 6, simulation on ADAMS–EASY5 co-simulation platform based on 360*MN* extrusion machine is given to verify the effectiveness of this new protocol and compare the performances of two protocols (consensus predictive control and consensus control). Finally, conclusions are drawn in Section 7.

2. Problem description

2.1. 360MN extrusion machine

360*MN* extrusion machine is an under-drive press structure machine Fig. 1. Six cylinders are placed uniformly as regular hexagon under the machine's crossbeam (main table) and push the main table upward to finish the extrusion process. The main table may tilt while rising during the extrusion process. Many reasons may cause tilt, including different roughness of surface, irregular in shape, uneven of metal structure, billet locating off-center and so on. The tilting may lead to eccentric or bend and has very negative influences on product quality as well as the serving life of the machine.

Fig. 1. The 360*MN* vertical extrusion press and the large-diameter thick-walled seamless tubes.

The hydraulic system of 360*MN* extrusion machine is driven by pumps as shown in Fig. 2. Four digital position transducers placed at main table's four corners send position data to central controller. With these signals, main table's attitude can be obtained. Meanwhile, six cylinder pressure transducers (each in one cylinder) collect the extrusion force signal for the controller as well. The attitude of main table is determined by the cylinders. So it can be controlled indirectly by regulating the variable pump's open degree.

360*MN* extrusion machine uses SIMATIC S7-400 process controller as its electronic control platform to meet the production demand of stabilization and high speed calculation.

2.2. Mathematical model of extrusion machine

In order to design and analyze control strategy conveniently, a simplified mathematical model for the extrusion platform is proposed. The main table is simplified to a disk (circle plane) with N hydraulic cylinder uniformly distributed around it. So it is naturally assumed that motion characteristics of the disk satisfy the rotation dynamics equation.

As shown in Fig. 3, there are two hypothetical perpendicular axes, through the center, on the disk called α and β. The intersection angle between axis α and the horizontal plane is φ_α and the angle between axis β and the horizontal plane is φ_β. Corresponding angular speeds of those two axes are ω_α and ω_β.

The disk is in balance if and only if Eq. (1) is satisfied. The control method aims to maintain this equation during the extrusion process. Agent i exerts a force to drive the disk upward. The central angle between agent i and negative direction of α axis is $i\delta$ as shown in Fig. 4. It is obvious that $\delta = 2\pi/N$ is central angle of any adjacent two agents:

$$\begin{cases} \varphi_\alpha = 0 \\ \varphi_\beta = 0 \end{cases} \tag{1}$$

Thus the discrete state equation of disk (2) and relationship of position parameter and angle parameter (3) can be obtained as

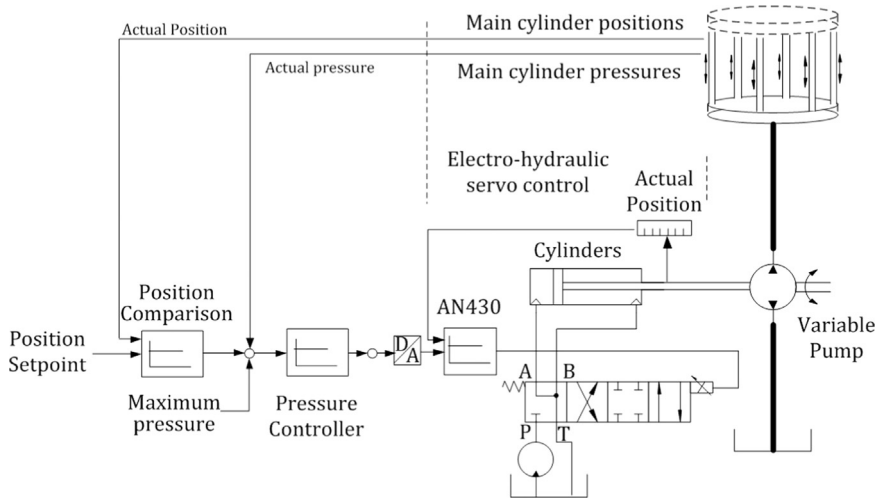

Fig. 2. The hydraulic control system.