Reconfigurable Machine Tools in Industrial Manufacturing Processes

LogDynamics
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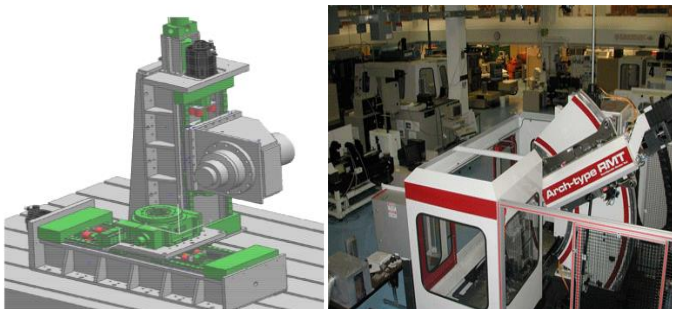
With today's enhanced globalization and worldwide competition, manufacturing enterprises are confronted with the challenge of being responsive to changeable market demands while maintaining a costeffective level of production. Global competition drives customers to purchase customized products more frequently and causes fluctuations in demand. Traditional manufacturing cannot meet those challenges. The dedicated machine is designed to produce a single product with high efficiency, but usually does not operate at full capacity with the increasing pressure from global competition. Computer Numerical Control (CNC) machine that can produce a variety of products with flexibility, but it is very expensive and its production capacity is much lower than that of dedicated lines. Hence, it is desired for manufacturer to react to customer demand rapidly and increase flexibility under such circumstance.

To cope with this issue, some burgeoning and advanced concepts related to manufacturing have been presented, e.g. reconfigurable manufacturing, cloud manufacturing, and predictive manufacturing. In particular the development of machine tools and reconfiguration science, which are taken into account for the basis of the industrial manufacturing processes in this era of global competitiveness. Capacity adjustment is one of the major approaches in industrial manufacturing and logistic processes to react on fluctuations in demand. To the end, we focus on the systematic analysis of the potential of Reconfigurable Machine Tools (RMTs) and the development of control strategies utilizing the dynamics of manufacturing and logistic processes for a sustainable demand oriented capacity allocation with uncertainties.



Prototypes of RMT

Problem Definition

Compared with traditional machine tools the reconfigurable machine tool (see some prototypes of RMTs below) is designed to be adjustable to demand fluctuations, and functionally adaptable to the introduction of new products. In other words, its' capacity and functionality is not fixed but may change over time to meet the demand.

The capacity of the production system includes three aspects, the capacity of space, the capacity of time, and the capacity of manufacturing. An adjustment of capacities is done by reallocating work force or utilities to temporarily in-/decrease the capacity, i.e. via flexible staff, extra hours or the rate of production, which are all comparably expensive. In contrast to that, reconfigural machine tool can change capacities by adding or removing modular components.

Manufacturing systems with a high percentage of parallel machines are of particular interest, which is a characteristic of job shop manufacturing (the figure on the next page illustrates a representative example of job-shop system). Due to small lot sizes and a large variety within series, respective companies will profit from the usage of reconfigurable machine tools and corresponding control strategies. For such a setting, the following assumptions are reasonable and will be used within the project:

- The percentage of reconfigurable machines is fixed.
- Machines are reconfigurable in less than two hours.
- The demand fluctuations are Gaussian distributed.

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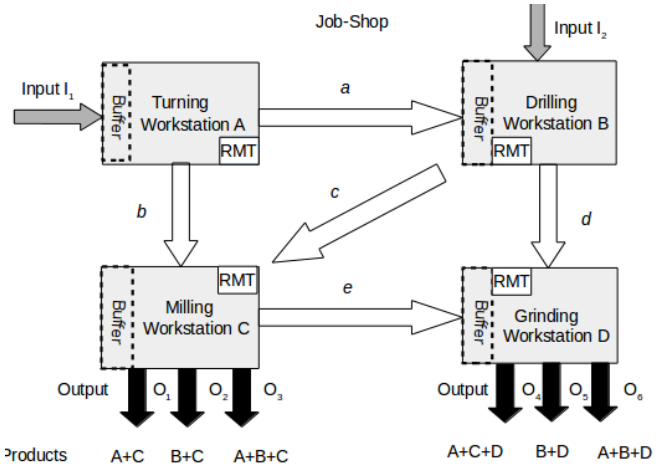
As the capacities of all shop floors shall be considered at once to avoid shortages and unused capacities of different shop floors, a central control instance is appropriate. To this end, the derivation and parametrication of different strategies or logics to trigger and execute the control must be analyzed.

The overall goal of the feedback is:

- Damping of negative effects of internal and external demand fluctuations.
- Improvement and reliability of the logistic efficiency of the manufacturing system.
- Realization of a sustainable layout, short processing times with low variance and adherence to delivery dates.



Flow in an exemplary job-shop system

Research Objective

The objective of this research is to extend the ability to react to demand fluctuations in the medium and short term. To this end, reconfigurable machine tools as well as new possibilities with respect to planning and con-trol of the capacity shall be employed. The simple usage of such innovative tools may improve adjustment of capacities and loads. Yet, an extension to cover a time planning horizon to incorporate load balancing will drastically improve the key performance indicators. Since the RMTs are investigated in a job-shop system, there is a need to model and analyze the properties of reconfigurable machine tools based on the previously developed manufacturing model. Utilizing the dynamic model of the manufacturing processes with RMTs, a centralized control system is required to be developed and implemented to reduce the external and internal disturbance. The combination of eventbased simulation and mathematical model is able to consider economic benefit and economic and manufacturing constraints simultaneously. Last, it is difficult to obtain the accurate model due to nonlinear nature of the process. Hence, we will derive a robust control to stabilize the system and guarantee the performance with uncertainties.

Solution Approach

As reconfigurable machine tools are the basis of this research, its current and future properties shall be investigated to support the entire project. The aim is not to go into full detail of all machines available in the market, but to focus on properties which are relevant regarding capacity and functionality. As for the mathematical model, we design a nonlinear state space model, which is discrete in time but continuous in states and subject to control inputs and unknown disturbances. Based on the model, a feedback control system shall be designed incorporating key performance indicators and constraints by using an optimization based controller, in particular model predictive controller. Moreover, we will analyze the properties of the closed loop with respect to sensitivity regarding parameters such as initial conditions, performance indicator weights and others. Last, we utilize the sensitivity results to develop guidelines for practitioners.

In the context of manufacturing process control, the number of RMTs could be chosen as control variable, and work in process (WIP) level as the controlled variable is essential for all key performance indicators. The aim is to balance capacity and load by assigning RMTs. In addition, the following points should be taken into consideration. Firstly, the reconfiguration delay caused by RMTs is ambiguous, which is actually determined by comparison of adjacent states. In other words, the delay is only trigged when there exists a requirement for increasing the number of RMTs. Otherwise, there is no delay. Secondly, integer assignment of RMTs within job shop systems cause the optimization problem to be NP-hard, which can be solved by analytical (e.g. branch and bound) and meta-heuristic methods (e.g. genetic algorithm). Furthermore, the stability of predictive closed-loop control system should be guaranteed, especially under the integer constraints and dynamic flow conditions. This can be implemented by terminal endpoint constraints, terminal cost and terminal constraints, and without terminal conditions.