Article Title: System Design of PLC-Controlled Specialized Production Machines

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Abstract: PLC-controlled specialized production machines are usually employed to automate customer-specific production processes. Sequential engineering processes are frequently used for designing these machines. To reduce the time and effort, parallelization of the different disciplines as well as increasing the reuse of already designed modules has to be considered. Both of these activities originate in the system design phase. Therefore, the sequential design process is analyzed to define the information required for starting detailed engineering in parallel. Additional requirements in the system design phase are derived from the characteristics of the system design phase itself and the special situation when designing specialized production machines. A method how these requirements can be fulfilled is shown based on these requirements.

Keywords: PLC, System Design, Systems Engineering, Specialized Machines, simulation, modularization.

1 Introduction

Shorter product lifecycles result in the challenge of achieving short times-to-market for new products. Further, the individualization of products is increasing and machines are needed to manufacture these products. Based on the individualization of the products, the manufacturing technologies employed have to be adapted. This turns into challenges for machine builders to deliver customer-specific machines in a shorter time. When using a sequential engineering process, the different discipline-specific phases cannot be shortened furthermore. However, to still reduce time, the various phases could be parallelized. Another approach that some machine-builders are using is a modular-machine design, which separates the development process into a module development process and an order-dependent development process. In this case, the machine is individually adapted to the manufactured product by combining different modules. For this reason, a minimum number of built modules is necessary. But some products require high customer-specific production technology, which cannot be achieved by just combining different modules. Therefore, specialized production machines are built. Based on the very customer-specific production technology and the fact that the product is highly dependent on the production process, only one or two of these types of machines are built.
2 Current Engineering Process for Specialized Production Machines

Specialized production machines consist of purchased components such as motors, sensors and mechanical parts, designed by the machine builders themselves. To automate the machine, programmable logical controllers (PLCs) are used. The current design process starts by defining the customer’s requirements regarding the machine. Here, the most important requirement is the specified cycle time for executing the manufacturing process. Based on this, mechanical engineers start by drafting possible solutions to fulfill these requirements. They are usually sketched by hand and implicitly contain information about the actions required, rough geometrical descriptions of parts, the first definition of assemblies, kinematic dependencies and module states during operation. This definition of a principle solution has a significant impact on the detailed engineering in other disciplines [2].

The next phase of the mechanical design process is characterized by detailing different geometrical parts in a mechanical CAD system (MCAD), where assembly groups are first defined. This detailed engineering goes hand-in-hand with defining the kinematics, the drive concept, the moved masses and the kinematic states within the process. The actuators to be ordered are calculated from these definitions and the required motion time between the kinematic states. The last mechanical engineering phase involves the detailed engineering of the different parts and assemblies. Specifying the sensors and actuators to the electrical department marks the transition from the mechanical engineering to the electrical engineering department. Here, the electrical engineers create what is known as a functional structure in an electrical CAD system (ECAD) and add the sensors and actuators specified by the mechanical engineering department. In this phase, each sensor and actuator can be directly mapped to symbols in the circuit diagram.

Further, the engineers must know the sequence of operation for the sensors and actuators, e.g. if two pneumatic cylinders should extend at the same time; however this can only be controlled if there is a common valve for both cylinders. Based on this information, the electrical engineers draw circuit diagrams. Once all of the signal interfaces of the devices being used and the mechanical results (mechanical design, kinematic information etc.) have been transferred, the automation department starts to define the various machine states. These states are generally kinematic states, e.g. “cylinder is extended” and the associated transitions, e.g. “cylinder extends”. Further, the transition conditions between the states are defined using the signal interfaces of the sensors being specified by the mechanical and electrical engineering departments. Detailed engineering adds additional states and transition conditions along with safety functions such as interlocking conditions. The machine is finally assembled and commissioned.

As mentioned previously, the decision regarding the principle solution has a significant impact on all of the disciplines involved. To obtain the best “mechatronics” solution, all disciplines should be involved in the system design phase [8]. Based on the individual customer requirements and the situation, the mechanical engineers frequently do not know whether a module has already been developed that can be used in this project assemblies, once developed, are infrequently reused [10]. The decision regarding the ability to reuse modules is also made directly by defining the principle solution. To reduce time within such a process, it should be possible to reuse modules as well as engineer new modules in parallel. To achieve both of these objectives, a method for designing the concept is needed before the various disciplines start detailed engineering in parallel.