A dynamic paper machine simulator for testing of model predictive control applications

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ABSTRACT

A dynamic paper machine simulator has been developed for testing of model predictive control (MPC) applications. The testing of functionality and preliminary tuning of the control applications in an automation system can be performed using the simulator. This facilitates the implementation work of the applications. The simulator contains an interface between the automation system and the simulator. The interface includes measured and manipulated variables of the control applications and the parameters and initial state of a model which the simulator used. The model has been developed to scale and flexible. The same simulator application can be used to describe different paper machines. The amount of the short circulations can be edited to correspond to represent a modelled paper or board machine. The order of the submodels of the drying part can also be changed. The model is mainly based mass balance and differential equations containing dead times and time constants.

1 INTRODUCTION

The paper making process has several different measuring devices and actuators which are used for the collect information about the state and the control of the process in order to ensure that the paper products stay within their specifications. There are several measured and manipulated variables which are often strong interactions between to each other. The change or disturbance in one variable is usually seen also as a change in several other process variables and properties of the end product. Some of the typical characteristics of the paper making process also are the nonlinearity and the long variable transport delays. In addition the combination of fast and slow dynamics is typical of paper making processes and other industrial processes.

MPC is an obvious choice for paper machine control because it can be systematically handle the coupling between process variables and time delays. Physical constraints of actuators can also be taking into consideration the controller design. The clear trend is for MPC to become the significant choice of the control methods in pulp and paper industry. [1,2]

The implementation of the MPC application is multiphase. The control objectives and the size of the problem must be defined. It also be determined the relevant controlled (CVs), manipulated (MVs) and disturbance variables (DVs). The systematic testing of the interactions of these variables requires by varying MVs and DVs and capture and store data which show how CVs respond. The MPC application needs predictive models and initial tuning parameters which must be determined and tested using the stored test data. [3] The data transfer and interface of the application must be also tested. At these stages the process simulator accelerates implementation work. Furthermore, the testing is safer on the simulator compared to a real destination process. It is easy to continue possible additional tests and tuning to the real process when the application has been preliminary tuned and tested with the simulator.

Several dynamic papermaking process simulators and models can be found in literature. [4,5] The type and structure of the models are often determined by the purpose of use and by the source information.

2 MODELLING

The model is the core of the developed simulator. This model which describes the paper machine in the machine direction is mainly based mass balance and differential equations containing dead times and time constants. Physical equations give a versatile and comprehensive test environment for control applications. The aim was to make a simple model but sufficiently accurate. The simple and clear model structure increases the usability. When the complexity of the model increases, the number of the needed model parameters will usually increase. The model has also been developed to scale and flexible when different paper machines can be modelled easily using the same simulator. The presented model includes the main stages of the paper machine: short circulation, press section and drying section.

2.1 Short circulation

The short circulations model contains the most important subprocess as a thick stock section, a mixing point, an approaching system, a headbox, a wire section and a wire pit. Figure 1 illustrates the structure of the short circulation model. The figure is the screen capture of the presented simulator. The thick stock section feeds the papermaking stock to the short circulation. The modelled stock includes some stock components. The mixing point merges the flow from the thick stock section and the white water from the wire pit. The filler components are also added to this point. The approach system cleans stock to the headbox. The small part of the stock is goes away to the reject. Retention aids are usually added before the headbox. Using these aids it can be influenced retention which is a measure how much stock material remains on the papermaking wire. The headbox distributes the papermaking stock uniformly across the moving wire where the main part of the water and the small part of the stock components is drained and sucked out through the porous screen into the wire pit. The part of this so-called white water flows to the long circulation, but the main part of the white water flows through the wire pit into the mixing point. The paper web which has stayed on the wire continues for a press section.

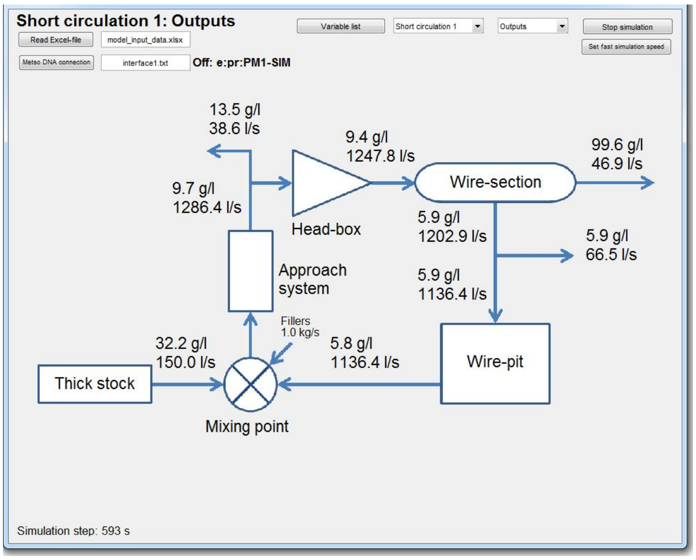

Figure 1. The simplified structure of the short circulation model (the screen capture of the simulator).

The model supposes that the volume flow does not have dynamics in the subprocesses. In addition to the water the modelled stock includes one fiber and three filler components. The short circulation model includes the dynamics of the consistencies of these four components. There are also modelled four retention aids to each fibre and filler component. The models of the thick stock section, approaching system and wire pit include plug flow and ideal mixing or/and zones. Delay times and first order time constants are determined by volumes and volume flows for these zones.

The headbox model includes the slice opening and head box pressure, which are manipulated variables. The jet speed is estimated as a function of pressure and the stock density. The mass flow through the headbox is further defined with the jet speed and some construction parameters. The dynamic of pressure change is modelled using the small time constant.

The modelled retention of the stock components is proportional to relative retention aid flow and dry mass flow of each component. In the calculation the normal situation is determined to the retention and how the deviations affect it. The wire section model includes a short time constant and change rate limits for the machine speed actuator. Retention aid flow actuator models are implemented as the first order transfer function.

Paper board machines can contain several parallel short circulations. The layout of the short circulation model is fixed, but the amount of short circulations can be changed in the simulator. The model is scalable in this relation.

2.2 Press and drying sections

The press section removes much of the remaining water by rolls pressing against each other. A part of the water is pressed away from the paper web between the rolls. The next section of the paper machine is a drying section, which dries the paper web by way of series different type dryers that evaporate the moisture.

The press and drying section models includes the dynamics of three basis weights [g/m2]: water, fibres and fillers. The last basis weight is the common for three fillers from short circulation(s). The web temperature is also calculated after each drying section units. The main part of the dynamics causes from the transport delays of the web. The simulator user can edit the layout of the drying section. The edited model can contain different type dryers and one type coaters. The modelled dryer types are a steam cylinder group, an air dryer and a general type dryer. For example infrared dryers can be modelled using the general type dryer models. The press section is also modelled.

The drying of steam cylinder group model has a simplified calculation based on relative changes at the operation points. The affecting variables are the web speed and steam pressure for each group. Steam temperature and contact heat transfer coefficient between cylinder and paper web are also calculated. The heat transfer coefficient depends on web moisture ratio. Effective steam pressure is supposed to include a first order model with time delay.

The air and general type dryers are also modelled using first order models with time delay. The manipulated variables of the coater model are the blade load and angle which affect the coating addition to the paper web. The coating is defined as fillers in the model. The evaporation rate and web temperature increase are depend the web speed. These interactions are also determined in the model.

3 IMPLEMENTATION

The simulator has been built using MATLAB by MathWorks. The source code of the developed simulator includes several MATLAB functions, which made the flexible revisions of the model structure possible. It is easy to edit the structure of the model according to the structure of the modelled target machine. The executable file can also be generated from the source files. Figure 2 represents the hierarchy structure of simulator. The scheme contains the self-made functions.

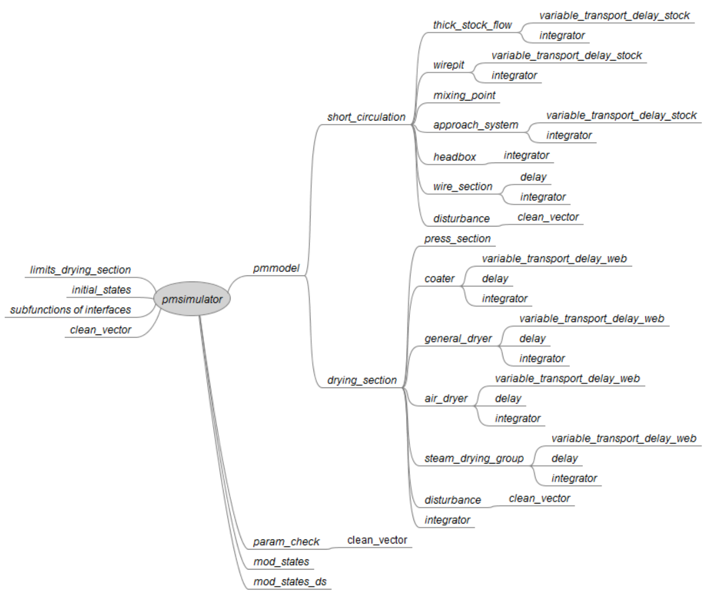

Figure 2. The hierarchy structure of the simulator.

The simulator main function (*pmsimulator*) and some other subfunctions include the graphical user interface and the interfaces of Excel file and the Metso DNA automation system. The MATLAB-based graphical user interface is own of the simulator. Figure 3 illustrates two views of the graphic user interface window. Moreover the automation system side is own displays to the simulator. The main function calls the model function (*pmmodel)* which contains submodel blocks of the paper machine model. These functions are divided model sections of short circulation (*short_circulation*) and drying and press (*drying_section*) sections. These functions connect and build the structure of the model by joining inputs and outputs from the submodel functions. Each functions correspond to each submodel blocks as headbox, wire section, steam cylinder group etc. Furthermore, there are some functions (*limits_drying_section*, *initial_states*, *param_check*, *mod_states*, *mod_states_ds* and *clean_vector*) which handle and check the values of the model parameters, inputs, outputs and states. The disturbance function (*disturbance*) generates different disturbances as random noise, sin waves and steps on the model. The place of the source of disturbance can be chosen and variable which the disturbance affects directly.

The submodel functions were encoded to the integrator (*integrator*) and the time delay blocks which are three types: the variable transport delay block for stock flow (*variable_transport_delay_stock*), the variable transport delay block for web (*variable_transport_delay_web*) and the constant delay (*delay*) block for actuators. To all variable transport and constant delays the maximum delay memory buffer size has been specified. The length of the maximum delay time is determined by the multiplication of the size of the buffer and the used simulation step time. For example, when the length of the buffer is 1200 and the sample time 0.1 s, then the delay time can be 120 s in its maximum. The lengths of the variable transport delay times are calculated during simulation as a function of the stock flow speed or web speed. If a buffer becomes full, then the last part of the delay is changed into a time constant.

The state values and delay buffers are handled with on vectors. If necessary the values can be saved from the model and can be loaded into the simulator via the interface between the model and the automation system. Furthermore, the interface contains the parameter vectors, input and the outputs vectors and other vectors which are related to the use of the simulator. It is also possible to simulate without the Metso DNA. In that case the parameters and input variables of the simulator will be defined from an Excel file.

The lower and upper limits have been defined for the values of the model parameters. The limitations intend to avoid the simulation problems. The values of the parameters and output variables are automatically checked during the simulation. The faulty values are marked into the graphical interface screen. The failure message also is sent to the automation system if the connection is operational.

The interface between the paper machine simulator and the automation system is based on a shared library by Metso. The connection between the simulator and the automation system is implemented so that the shared library, once initialized, starts a new application server as a part of the existing automation network. The library can be used to access data of basic Metso DNA data types and generic tables. The data transfer is managed with vectors. From Figure 3 (the left screen capture) for example the parameter vector values of the first short circulation model can be seen. The data transfer sample time between the model and MetsoDNA can be determined separately. There are own vectors of the model parameters, inputs, outputs and states for each short circulation models and drying (and press) section model. Furthermore, there are interface vectors, which are accompanied by the use and diagnostics of the simulator.

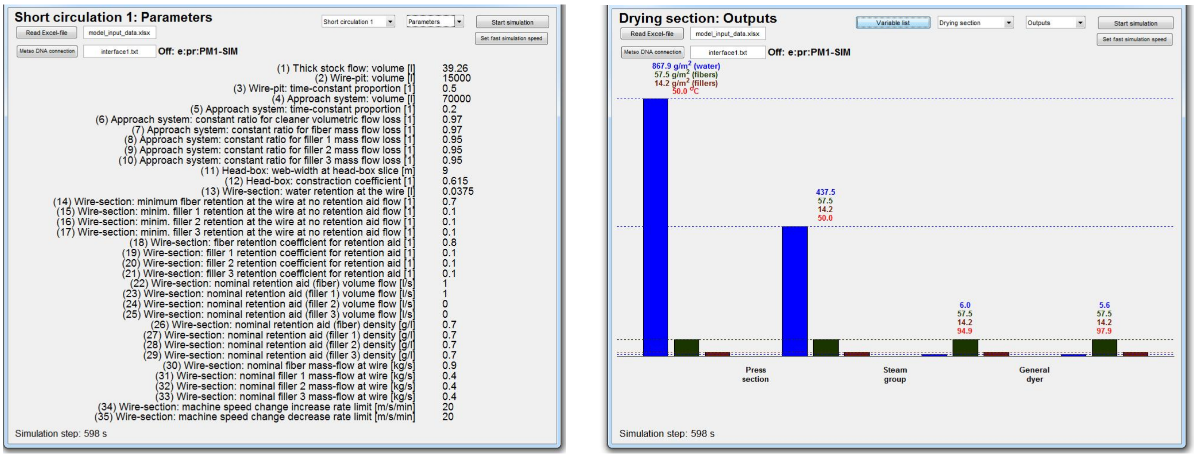

Figure 3. The two views of the graphic user interface window.

4 CONCLUSIONS

The presented simulator is a workable test bench for the testing of the control applications. The functionality of the applications and data transfer in the automation system can be tested using the simulator. The paper machine model which the simulator used has been developed to scale and flexible and easy to use by the automation system and the graphical user interface.

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