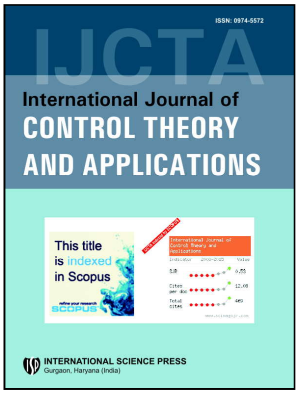

International Journal of Control Theory and Applications

ISSN : 0974-5572

Volume 10 • Number 18 • 2017

Control of the Paper Making Subsystem–A Brief Review

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Abstract: Paper has become an essential commodity material and has variety of applications such as writing, printing, packaging, from kitchen to industries. There are various qualities of paper used around the world. Modern era is seeing paper as a basic material that finds its use in almost all the areas around the globe. With the advancement of technology, high speed paper machines have been developed for the manufacturing of high quality paper. The quality of paper majorly depends on the functioning of most important subsystem of paper machine which is Headbox. Headbox plays an important role in boosting the economy of a pulp and paper industry. There has been substantial research on the paper machine headbox. This paper presents a brief review of the control techniques proposed and developed and applied on the paper machine.

Keywords: Paper machine, Headbox, Robust Control, Intelligent Control

1. INTRODUCTION

The first paper was developed around almost 2000 years ago in China [63]. Paper making plays a vital role in adding billions of dollars to the world economy annually [64]. The most important subsystem of the pulp and paper making process is paper machine [13]. The most important element that plays a vital role in paper manufacturing is the paper machine which continuously convert the cellulose fibers and slurry of water in an efficient way [64]. Many modern paper machines are based on the principles of the Fourdrinier Machine. Major components of Fourdrinier paper machine are: Flowspreader, HeadBox, Fourdrinier Table, Presses, Dryers, Calendar, and Reel [65] as shown in figure 1. The process of making paper is a highly complex process of heat and mass transfer. Also it is nonlinear process which has the distributed parameters [13]. The need of high quality paper continuously increasing which has resulted in the design and development of paper machines with high speed and better efficiency [23]. The paper machine operation is completely defined by the modeling and control the process. Being a highly complex process and various mandatory requirements (such as quality, low cost, safety and environmental concerns), the paper making process now requires a high performance advanced control for the enhancement of the overall process operation. A paper making process is not a single variable process. It includes several sub processes which are highly inter-related to each other and need to be controlled

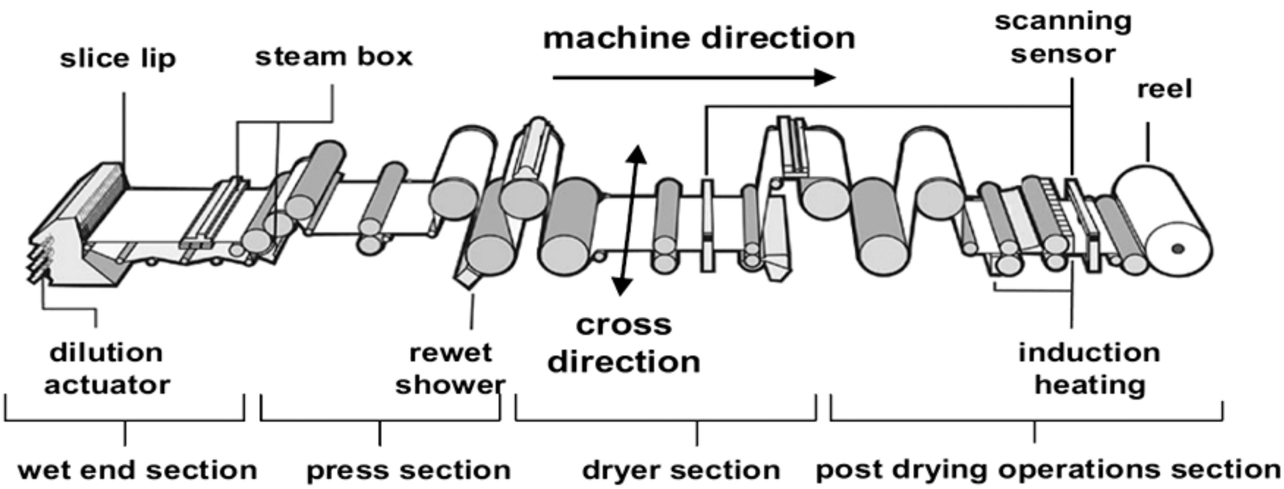

Figure 1: A broad view of Fourdrinier paper machine showing all sections [64].

efficiently through a proper cooperation among each subprocesses [23]. One of the most important sub system of the paper making process is "Headbox". Headbox in a paper machine is intended to cause a steady state movement of pulp to wire. Important step in the paper making process is the stock material which is uniformly distributed on the wire through headbox [22].A headbox is categorized as open type headbox and pressurized headbox. Further a pressurized headbox is categorized as air cushioned and hydraulic type headbox.Since the quality of the final product (i.e. paper) is largely influenced by the operation of headbox, so its precise control and monitoring is highly required.

The forthcoming section discusses about the aspects of the control of paper machine headbox. Figure 2 illustrate a general working of paper machine headbox.

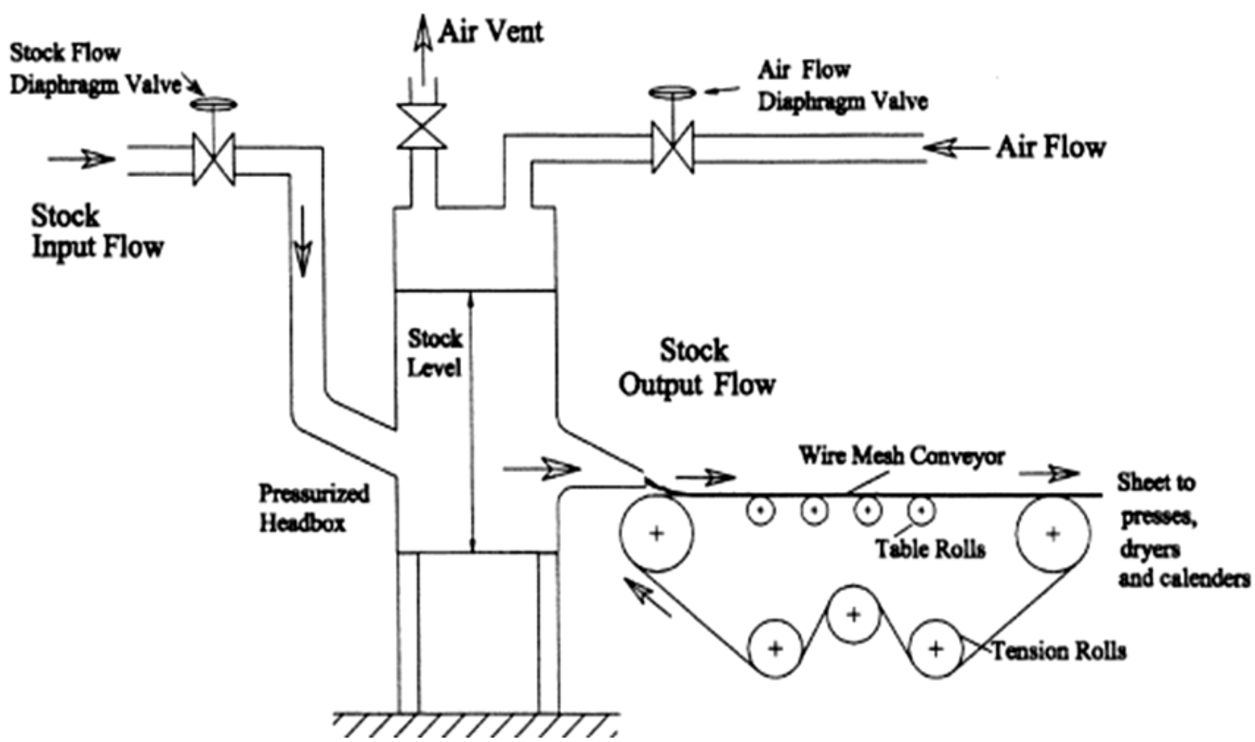

Figure 2: Headbox arrangement [31]

2. LITERATURE REVIEW

The complexity and interactions in the paper making process and difficulty in measuring the major quality variables online, it is required to design such an advanced and robust control system that can ensure the stability of the process in presence of various disturbances and uncertainties. There has been a substantialstudy done on paper machine headbox control. Such as [1] describes about the various effects of headbox variables on the formulation of paper. An adaptive control algorithm has been developed in [2] for the control of moisture and basis weight in paper. The algorithm proved to be good for reduction in the losses and any variance in the moisture and basis weights of the paper. A multivariable controller for headbox has been proposed and designed using computer based designs such as Rosenbrock's Inverse Array Technique for controlling the pressure head and stock level of headbox [3], Extended Kalman filter and two stage estimation algorithm techniques have been used in [4], Self-tuning technique for moisture control in [5], [6] discusses the use of Kalman filters on pressurised headbox,bilinear control strategy which includes bilinear decoupling control, observer and disturbance compensator in [7], A systematic decoupling control of pressurised headbox was introduced in [8],A Models and on-line identification techniques was presented in [9], Robust GMV control for the cross direction control of headbox [10], Nonlinear predictive control in [11], An Internal model control with reference model was proposed in [12], [18], Robust control through loop-shaping design in [14], Generalized Predictive Control with Modified Smith predictor andInternal Model Control [15], Robust Control for CD response in [16], An object oriented control using modelling language OMOLA in [19], [20] describes a tuning techniquewhich is centred on the identification of the process and disturbance models, fuzzy-PID method in [21], MIMO digital-linear-quadratic-regulator in [22],The fragility issues related to the controllers and the aspect of robustness that has been neglected in analytical treatments of control system design of paper machine headbox is discussed in [23], Shape optimization and optimal control techniques were developed for numerical control of paper machine headbox flows in [24],The CD control limitations due to model uncertainty have been examined and discussed in [26], A technique based on discrete wavelet transforms for CD control has been described in [27], Effects of disturbances on first – pass retention and basis weight discussed in [28], A dynamic simulation of a paper machine wet end was presented.in [29], Design of CD control of paper machine through multivariable problem, Optimal minimum control effort for a Fourdrinier machine headbox in [31]. An adaptive model predictive control of consistency control [32], Spatially-distributed feedback controltechnique for CD control of paper machines in [33], A non-smooth biobjective optimization technique for the design of the shape of a slice channel [34], Interactive multi-objective optimization method NIMBUS [35],A simplified dynamic model for the wet-end in a paper mill was proposed in [37], Artificial Neural Networks based moisture and basis weight control in [38],Advanced control methods and decoupling algorithms [41],Decoupling and Time-delay Control Approach [42],A neural network (NN) based decoupling control technique has been developed in [43],Artificial neural network (ANN) based retention control [45],Adaptive fuzzy controller[46], Various controllers and tuning methods have been studied on paper machine headbox in [47]. Neural network decoupler control system [48], Model Predictive Control for consistency and liquid level control [49],GA based Neural PID decoupling control [50], Advanced prediction based control approach[51],Various PID controller algorithms for consistency control [52],A decoupling control system design [53], Non-fragile bilinear state feedback control [54]. A robust PID control technique have been designed and applied on paper machine headbox for the control of stock flow, air pressure & stock level [55], A robustness analysis of different controllers based on PID tuning methods have been discussed in [56] for the control of consistency, Optimal Linear Quadratic Gaussian control scheme used for controlling the pulp total head & pulp stock level of a paper making headbox system in [57] & [59]. MIMO control design for headbox using fuzzy logic control strategy in [58], fuzzy tuned PID control for nonlinear control problem in air cushion headbox in [60] and for the total pressure and stock level control of paper machine headbox [61].

3. HEADBOX CONTROL

Though there are many sub processes of the paper making process. However among all the sub processes, headbox (or Flowbox) is most important subsystem. Because of the technical and economic reasons, headbox has been the centre of attraction for many researchers in past few decades [13]. Total pressure head and stock level are two parameters which are generally considered for the control of headbox [3], [6], [7], [11], [12], [14], [15], [20 – 23], [41], [43], [48], [50], [51], [54], [55], [57], [59]. However apart from the pressure head and stock level, the other parameters major which are related to headbox control design are: headbox consistency, jet velocity, and rush/drag. Jet velocity and rush/drag are the calculated variables. Jet velocity is proportional to the square root of the total pressure head. Rush/Drag is the ratio of the speed of the stock out of the orifice of the headbox at the bottom and speed of the wire (i.e. Fourdrinier machine). It is also known as jet to wire ratio and has a significant influence on the sheet formation. Any variation in these parameters greatly affect the sheet properties. Headbox Consistency is an parameter which is of equal importance and can used for the designing the control techniques for headbox to enhance and maintain the quality of the paper. The reason to control consistency is that it can affect the dry basis weight [13]. However, from the literature survey it has been observed that consistency is the least considered and poorly understood parameter in designing the control techniques for headbox [47], [49], [52], [56], [65]. However, the paper machine headbox control is not free from various difficulties such as, there are certain unmeasurable process states, Long delays, Substantial variations in the parameters, Strong coupling and interactions between different parameters of the headbox, Uncertainties and process disturbances.

4. CONTROL TECHNIQUES USED FOR HEADBOX CONTROL

Many significant control methodologies have been developed and applied on headboxes, such as:

a) Adaptive Control[2], [32], [46]

b) Predictive Control[27], [49], [64]

c) Robust Control[10],[14], [16], [20], [55], [56], [57], [59]

d) Optimal Control[21], [22], [25], [31], [35]

e) Multivariable Non-linear Control[11], [26], [58]

f) Bilinear Control [7], [54]

g) Intelligent Control[38], [45], [60],[61]

h) Decoupling Control[8], [41], [42], [43], [50], [53]

i) Digital Control[2], [4],[22]

j) Internal Model Control[15], [18]

5. OBSERVATIONS

The following points have been observed from the literature survey as explained above

(i) Most of the techniques which have been discussed briefly in literature survey are based on the assumption of ideal headbox. These methodologies do not consider the effect of uncertainties and disturbances on the functioning of headbox.

(ii) Most of the research has been conducted on controlling of total pressure head and stock level in the headbox.

(iii) There is a slight discussion on the type of uncertainties affecting the operation of paper machine headbox. Few papers discuss about the uncertainty however are not specific about the uncertainties.

(iv) There are other parameters related with the paper making machine which can be controlled, however are least considered.

(v) One such parameter which is very important but least understood and considered in controlling the paper machine headbox operation is the headbox consistency.

(vi) Though there has been a significant research on the crucial subsystem of paper making process i.e. headbox. Many control algorithms have been applied on the control of total pressure head and stock level of the paper machine headbox. However, most of the research, as observed from literature survey, there are various algorithms which have not been applied on the paper machine headbox control.

(vii) Most of the research do not clearly highlight the presence of uncertainties in the headbox, their effect, and how to control the operation of paper machine headbox in presence of uncertainties.

(viii) Hybrid intelligent robust control techniques can be used on the paper machine headbox. Being the new technology, such control technique can prove to be revolutionary step in control of paper machine headbox under the effect of uncertainties and disturbances.

6. ADVANTAGES OF HYBRID INTELLIGENT ROBUST CONTROL TECHNIQUES

(i) Ill formulated problems can be easily modelled and controlled using the hybrid intelligent robust control

(ii) Since headbox is a system in which parameters are continuously changing. Hybrid intelligent robust control very useful to be used in such environments.

(iii) Uncertainties and fuzzy information can be easily processed by using hybrid intelligent robust control.

(iv) Hybrid intelligent robust control can be used in the fault diagnosis.

7. CONCLUSION

Headbox is the crucial element of paper machine. The control of headbox is important in a way that it eventually affects the economy of pulp and paper industry which depends on the quality of the paper produced. So, to ensure the quality of the paper to be high, it is highly important that the paper machine headbox is controlled efficiently. There are many techniques available and applied on the headbox for its control but most of them fail in the sense that no effect of uncertainties and disturbances have been considered. However, headbox is a multi-variable system which is highly nonlinear, complex and has continuously changing parameters. So, the conventional techniques and other robust techniques developed do not give significant results. Hybrid intelligent robust control techniques can prove to be revolutionary step in control of paper machine headbox due to various advantages of robust and intelligent control.

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