A REGULATION CONCEPT FOR WEB SPREADING EQUIPMENT IN WEB PROCESSING MACHINES ON THE BASIS OF NEURAL NETWORKS

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ABSTRACT

Web spreading systems are used in converting machines in order to guarantee a folding free web transport and a sufficient slit gap or slit separation. The adjustments, dependent on the respective application, are carried out manual before and during the operation. Wrong machine adjustments lead to productivity and quality losses. On this background a general regulation concept for web spreading systems, which is based on neural controllers is presented in this paper. The regulation concept is used for the regulation of the slit gap formation and applicated on the example of a dual spreader. The basic component of the controller is a controlling strategy which contains a mathematically describable, idealized operating range. All other, only qualitatively describable influence variables are declared as fuzzy data and included into the data base of the neural controller as training sets. First results show that neural controllers are suitable for the automatized operation of web spreading systems and can be drafted and simulated with passable operating expense.

NOMENCLATURE

B_0	width of the unslitted web
B	width of the individual strip
H_b	adjustable curve height
H_2	curve height of roller 2
L_1	distance between the bowed rollers 2 and 3
L_C	roller length
L_S	slit gap
r	radius of bowed rollers 2 and 3
R	curve radius of a bowed roller
R_2	curve radius of roller 2
R_3	curve radius of roller 3
n	number of slits
x	coordinate in cross direction (CD)
y	coordinate in main direction (MD)
Δx	size of the carry out effect
α	wrap angle

INTRODUCTION

In web processing machines it is the task of web spreading equipment to stretch the web diagonally to the main direction as well to create slits and to separate individual strips. To achieve these, various construction principles are in use with different mechanical adjust devices to realize the conformity for the respective use case.

Because the mechanisms of web spreading could not be registered close to reality, in spite of extensive theoretical and experimental investigations as well as practical experiences, no sufficient selection criteria for the respective use case, no complete selection criteria for the construction and no suitable control- or regulation parameters for the use of web spreading equipment are available up to now. As a consequence, productivity losses must be accepted, for example longer phases of attempt in grade- or format changes and quality losses, e.g. bulbous paper reels or intertwine individual strips and considerable rejects have to be booked.

With this background, a control system based on neuronal networks is introduced for the automatic regulation of web spreading equipment. This helps to avoid on the one hand production and quality losses for the respective use case and on the other hand manual adjustments of web spreading equipment.

FUNDAMENTAL KNOWLEDGE

Web transport belongs to the essential functions in web processing machines. It must suffice the different requests, which are expected from an optimal web path in the machine from process function to process function. These general requests are specified as follows:

web transport without wrinkle or web break,

uniform stress-strain-behavior in main and cross direction for the transported web and the individual strips,

sufficient web tension and lateral force for the respective processing functions (e.g. winding or slitting),

led web transport depending upon the required running direction.

In web transport courses, which are in processing machine usually equipped with rollers, these requests are first achieved with adequate regulated motor and brake systems to create the desired web tension in downstream direction. They fix the basis for the stress-strain-behavior of the web in main and cross direction. Normally it is not possible to achieve all lateral force requests of the web transport. Therefore, web spreading equipments are integrated into web transport courses.

In consideration of the described use of winders and cross cutters, web spreaders have two tasks in paper processing:

to strain (to stretch) webs with different width diagonally to the web running direction,

to separate individual strips from one another, to hold them under lateral force and to form a desired slit.

In order to achieve these tasks, rollers or bars with manifold construction principles are in use:

undivided or divided rollers (bars),

bowed, barrel shaped or fitted rollers,

fixed or rotating rollers (bars),

driven or not driven rollers (bars),
turned into web or tangentially positioned rollers (bars),
grooved and/or covered rollers.

All technical machine devices have in common, that the web spreading equipment is manually used and adjusted, whereby the adjustment is carried out mechanically, pneumatically or hydraulically. Control- or regulation units so far do not exist for automate adjustment processes, that means that on the basis of the subjective personal experience, machine adjustments can not be optimally performed during the process. Production and quality losses are the consequence, which are already mentioned in 1977 [1]:

unsuitable web spreading effects (too strong or too weak),
uneven web spreading effect by variation of the process parameters (e.g. web velocity or web tension),
insufficient web spreading effect at the web edges,
instability of the web path (e.g. oscillation or flattening),
uneven slit separation and development over the web width (intertwine of the individual strips).

Although the use of all web spreading equipment is based on the same physical principles, there is no sufficient knowledge, in spite of extensive theoretical and experimental investigation as well as practical experience, to understand the mechanism of web spreading and the error parameter during the process and to avoid the mentioned problems in web spreading through corresponding first adjustments and/or adjustments in the process. On the one hand this depends on the stress-strain-states of the transported web, which can only be measured insufficiently and on the other hand the web spreading behavior in contact with the rollers (bars), which can only be described under ideal conditions. Further web spreading equipment shows scarcely reproducible behavior, because the influence parameters in the process are a subject of steady variation.

REGULATION CONCEPT

With this background, it suggest itself to develop a regulation concept for web spreading with which, with use of a suitable regulation type and with consideration of well known physical connections and the use of various experience knowledge, an automatic operating of a web spreading equipment with regulated adjustments becomes possible. The presented solution for the regulation concept is based on:

1. **process range determination for the selected construction principle of a web spreading equipment on the basis of a mathematically describable, idealized physical model**
2. **detection of all not mathematically describable connections of influential factors through qualitative description and weighting of the influential factors**
3. **accumulation of all experience knowledge out of the web spreading process in a database and**
4. **selection and configuration of a controller, whose regulation field minimizes the effects of the error parameters on the basis of incomplete and fuzzy data.**

With use of different examples, these four basics of the regulation concept will be presented in the following.

DETERMINATION OF THE PROCESS RANGE FOR WEB SPREADING EQUIPMENT

With the knowledge of the process range for web spreading equipment and with consideration of all influence parameters, the physical connection between in and output data of a process status can be generally described. The influence parameters can be organized in three categories:

construction principles of the web spreading equipment: equipment, type, number and dimension of the web spreading elements as well as drive conditions,

material properties of paper: stress-strain-behavior in MD and CD, friction coefficient, permeability and moisture and

process parameters: web tension, -velocity, -width and single or several web(s).

Process Range Influence Parameter

To show the influence parameter coherences with the regulation concept, the dual spreader is used as an example. The dual spreader construction principle is in accordance with figure 1. Characterized by a roller group, consisting of four sequentially arranged rollers with a straight one at the web entry and exit and two bowed, turned into the web spread rollers between. To achieve slit separation and slit gap, the bowed rollers must suffice certain geometric requests, which determination is based on material characteristics and process parameters. In this figure, the geometric requests with their web spreading effects can already fundamentally be realized. The geometric criteria:

parallel web entry at roller 2 and web exit at roller 3,

same directed roller curves 2 and 3, perpendicular to the web entry and exit direction,

curve radius R_2 and R_3 in relation to the distance L_1 between roller 2 and 3,

web entry at the concave side of bowed roller 2 and web exit on the convex side of bowed roller 3,

force a web run, which produces the slit separation between roller 1 and roller 2, induces slit gaps between roller 1 and roller 3 and guarantees parallelism at the exit of roller 4. The named conditions and the geometric criteria are achieved, if the passings through webs have contact with all rollers. Therefore, slipping is not marked and the contact is characterised by static and kinetic friction. The static friction area is required to achieve the folding effect of web spreading and the kinetic friction area to produce the carry out effect.

The folding effect achieves a shift of the single webs without altering the cross straining and the development of slits. This is done by twisting the individual strips between roller 1 and 2 and/or between roller 3 and 4 as well as through wrapping at roller 2 and roller 3 [2]. The carry out effect achieves an addition of cross straining of the individual strips while running through the wrap from the concave to the convex side of bowed rollers 2 and 3 [2].

Idealisation of the Process Range

From these fundamental explanations of a dual spreader, it is already clear that an operating range, which considers all influence parameters, is only describable with an extensive idealisation and exclusively for a stationary state. Web transport through web spreading equipment is strongly non-stationary. Therefore, the state of friction between roller and web is strongly influenced, while its consistency is of great influence to the proper functioning of the spreading process. Considering a regulation model to describe the process a reduced mathematical model, incorporating only geometric criteria is needed as a basis for the regulation field. This means that all parameters influencing the state of friction, like material properties of the web (friction coefficient, permeability, moisture) and process parameters (web tension and velocity) are not taken into account for the mathematical description of the physical model. Instead, the kinematic dependence between input parameters (construction of the dual spreader) and the output parameters (slit gap of the exiting web) are mathematically described. To reach an optimal operating rate for the web spreading equipment an idealised operating range is developed by variation of the parameters.

Optimal web spreading conditions for a dual spreader arise, when the web path for slit separation is affected only by the folding effect and is neither influenced by bending moments or in-plane lateral forces. Additional bending moments and in-plane lateral forces occur when the geometric circumstances for the pure folding effect are not fulfilled, as shown in figure 2. Knowing that the web always enters and exits a wrapped roller vertically [3], a web path free of bending moments and lateral forces emerges, if the entry positions A and B on roller 2 and the exit positions C and D on roller 3 lie in one plane. With the help of a corresponding relation between the roller curves, this demand can be fulfilled. The corresponding relation is:

$$R_3 = R_2 + L_1 \tag{1}$$

Deviations from this relation between the roller curves, for example through enlarging the distance between the rollers 2 and 3 leads to a curved plane of the entry and exit positions with a static friction state at both rollers. This means that the web path is curved and leads to bending moments in the web plain. This additional web load leads to uneven tension and lateral force on the web edges, greatly influencing the effect of the web spreading equipment.

Based on these considerations for the optimal selection of the dual spreader geometric criteria, a simple mathematical relation to determine the slit gap L_S, see figure 2, while neglecting the influence of the carry out effect can be found:

$$L_S = x_3 - x_2 \tag{2}$$

Taking into account the actual use of a dual spreader with several slitted individual strips, the slit width can be calculated after:

$$L_S = \frac{B_0 \cdot (L_1 + 2r)}{n \cdot (R_2 - r)} \tag{3}$$

This equation is valid, if the additional condition of the bending moment- and lateral force free web transport with $R_3 = R_2 + L_1$ is fulfilled and the individual strips have their entry at the concave point A and the exit at the convex point D.

With this relation and wrap angle independent, an idealized operation range for a dual spreader is easily determined by variation of the parameters.

Dual Spreader Operating Range

In the following, a typical result of a dual spreader operating range will be shown. These results have been performed with the construction containing the bowed rollers 2 and 3 and the dimensions from figure 3. With the condition of an ideal roller adjustment (lateral force- and bending moment- free) and with neglect of the carry out effect the operating range from figure 4 is achieved for a slitted web with three individual strips (n=2).

In an interpretation of this operating range it is clear that the development of the slit gaps L_S are most effective when the modification of the bowed curves R_2 and R_3 can be build up with the formula $R_3 = R_2 + L_1$. The slit gap influence of L_1 (bowed roller 2 and 3) is now obviously fewer.

For the conception of a web spreading controlled system this operating range can be used as a basic principle for the configuration of the controller. Such a operating range is suitable for the basic settings of a dual spreader. The wanted bow radius R_2 of roller 2 and with that the bow radius R_3 of roller 3 can be easily determined from such a operating range if the required slit gap L_s, the roller distance L_1 (fixed by construction conditions), the predefined web width Bo and the predefined number of slits n are known.

DETECTION OF QUALITATIVE DESCRIBABLE INFLUENCE FACTORS AND PERSONAL EXPERIENCE

The development of a regulation concept demands the qualitative knowledge of the basic design concept for the idealized process range as well as all influence parameters and their interferences. With all these information, it is possible to consider them into the control system as error parameters. Additional to that a regulation concept can be improved, if empirical data from the production are included.

In consideration of the explained parameters it is clear, which one have only a quantitative influence on the web spreading effect. These factors are in interrelation with the non-stationary friction states between web and spreading devices. In all cases it concerns the influence of the transferable friction forces, which in dependency of the above mentioned three categories and with consideration of fundamental investigations / 4, 5, 6 / can qualitatively be described.

Influence of the Construction Principles

In a regulation concept the wrap angle has to be considered as a non-stationary influence parameter. If a static and kinetic friction area is present, in dependency with the wrap angle value the carry out effect is arising. During web transport in web spreaders it is well known, that the carry out effect has a strong character, if the curve direction of the bowed rollers is perpendicularly to the bisecting line of the wrap angle. Further, it is well known that the max. spreading effect is achieved by a web entry on the concave side with a following wrap of 180° and a web exit on the convex side of the bowed roller. For the example of a dual spreader, these realizations can explain the connection between the wrap angle and the carry out effect. The geometrical condition, parallel web entry at roller 2 and exit at roller 3 as well as bowed rollers in the same direction perpendicular to the in and out running web, are necessary for the folding effect and best conditions for the development of the carry out effect.

The analyse of the wrap angle and the web path (figure 1) in a stationary process results in a trigonometric function, which shows the dependency between the carry out effect and the wrap angle in accordance to figure 5 [7]. The standardized course of the carry out effect corresponds to the function $(1 - \cos\alpha)$. The web course runs at both rollers from the concave to the convex side. The result is a positive carry out effect, which corresponds to an increase of the cross stretching in CD. The marked entry and exit points A and B for roller 2 or C and D for roller 3 define the attainable carry out effect. For the construction already introduced in figure 3, the individual strip with a width B = 1.200 mm, rollers distance L_1 = 380 mm, curve radius R_2 = 165.7 m and a wrap angle of α = 45°, a carry out effect is approximately achieved of 0.4 mm, which corresponds to a cross stretching of 0.3 %. That means, that the carry out effect decreases strongly with small wrap angles and with non-stationary process states (temporary web slipping with high production velocities and web tension changes). In the worst case, the carry out effect and the corresponding spreading can be lost. Therefore, a regulation concept should contain a sensitive regulation component for the web tension, which considers the changing friction states in the wrap angles.

Influence of the Material Properties

Further important influence categories on the effect of web spreading are the material properties of paper. These influence directly and indirectly the state of friction between web and spreading elements and with that, they lead to non-stationary process states. In this context, the transferable friction force can be used as a characterizing size for the description of this non-stationary process state. Up to now only few strongly idealized mathematical models and only few experimental measurement results are available for the description of the relationship between material properties and transferable friction forces.

The anisotropical stress-strain-behavior of paper takes influence on the Young`s moduli in main and cross direction and with consideration of the Poisson`s ratio on the transferable friction forces in the same directions. The greater Young`s moduli are, the greater are the friction forces in both converting directions and the greater the value of Poisson`s ratio in the webs plane is, the greater is the friction in CD.

Additional to the normal force between web and spreading elements the friction coefficient as a material surface property is of great importance. As long as mechanical contact between web and roller exists, the transferable friction force can be determined in a simple way using Eytelwein`s formula with a known friction coefficient. Due to higher web velocities or reduced web tensions the web passes through a fluid friction area and there is no more mechanical contact between web and roller. That means that in this state there is no more perpendicular in or out running of the web into the spreading unit and with that no spreading effect. Starting from an optimised roller surface for the maintenance of a maximum friction coefficient, e.g. a rough, wear resistant surface as well as channels for the removal of the entrained air volume, the web tension is the only remaining parameter to be used for the regulation concept.

Further influences result from the permeability and the moisture of the web. Both parameters are influencing the friction coefficient and with that the transferable friction forces. It can be recognized that have, in dependence of the webs velocity, a massive influence on the transferable friction forces. With increasing permeability and increasing moisture the friction coefficients increase themselves. Since these influence parameters must be considered as disturbance variables, they have to be included into the regulation concept. With the condition of an optimal roller surface, the web tension is again suitable as a controlling variable for an automatic controller.

Summarized, for the material properties can be observed, that for a regulation concept it is only reasonable to consider "long-wave" variations of the material properties. "Short-waves" or volatile modifications of the material properties can not be stabilized either with the readjusting of the web tension or with the readjusting of the spreading elements, due to the necessary adjusting-times.

Influence of the Process Parameters

Process parameters, like web tension or web velocity, are the most important influence parameters on the web spreading effect. They have a contrary influence on the friction states between web and rollers and with that on the transferable friction forces. The friction forces increase with rising tension and decrease with rising web velocity.

Because the further process variables, specially the web width and the number of slits are fixed by the production conditions and the web velocity can be used only limited as a controlling variable, the web tension becomes, next to the geometry of the spreading elements, the most important controlling variable in the regulation concept.

The accumulation of empirical values from the practice is used for building up control equipment and/or learning databases for innovative regulation concepts.

CONFIGURATION OF A CONTROLLER CONCEPT FOR WEB SPREADERS

The regulation concept is based on of the described four categories for the chosen strategy. The aims of this choice are the selection of a suitable regulation type and the development of a process model, based on an idealized operating range and otherwise on incomplete and fuzzy data. In web processing machines, this development achieves an automatically setting of the web spreaders by the use of relevant process parameters for the pre-adjustments. During the process, manual interventions inflected by various disturbances, should no longer be required.

The aims of the regulation concept are:

- wrinkle free web transport for webs and individual strips as well as
- sufficient slit separation and gap development for the individual strips

With the reference model of the automatic control loop (figure 6) the resulting regulation components are:

controller: determination of the manipulated variable with suitable control algorithms,
controlled system: simulation able process model for web spreading,
command variable (set value): fixed stress-strain-ratio in MD and CD and/or width of the slit gap,
controlled variable (actual value): stress-strain-ratio in MD or CD and/or width of the slit gap from measurement or simulation,
controlled difference: difference between set value and controlled variable (input data of the controller),
manipulated variable: correction value for the adjustment of the web spreader or the tension as an initial value for the controller and at the same time as input of the controlled system for the activation of the control drive,
error variables: influence parameter of the construction, altering material properties and the changing process parameter as an additiv element,

In reality, a measuring and an adjustment component are necessary for the implementation and operation of the control loop. A report about the realization of the named components is yet not possible, because the research is not finished.

SELECTION OF A SUITABLE REGULATION TYPE

The selection of a suitable regulation type depends on the quality of the simulation process model of the controlled system and on the required regulation quality.

The classical control engineering assumes that the process model can be mathematically completely entered. The model is usually described by differential equations. Therefore, the quality of the process model depends on the accuracy of the mathematical formulation, which describes the physical connections. The regulation quality is a subject of similar conditions. A criterion for the evaluation quality is the error response behavior of the controller. A mathematical description of the transfer behavior is supposed. The conventional available controllers for this task (P -, I -, PI and PID) are limited or not at all suitable for the regulation of web spreaders. Related to the deduced bases for the dual spreader example, the mathematical connection of the idealized operating range for stationary operation (viz. (3)) would only be available for the description of the process model. Beyond that, the regulation quality for the required gap accuracy would not be achieved due to the complex friction states. Another problem is the inflexibility of standard controllers. They permit only a small number of adjustable variables. From this it can be concluded, that conventional controllers are only suitable for elementary transport functions (e.g. web guidance in a group of rollers).

The modern control engineering has the target to solve a control process with methods of processing fuzzy information and by neglecting on the one hand the explicit mathematical description of the controlled system and on the other hand the precise knowledge of the physical interferations between error variables and controlled variables. As a far developed representatives of this controlling strategy the fuzzy and the neural controllers are to be mentioned. Both controlling concepts have the mentioned advantage, not to describe the physical interferences explicitly and are therefore fundamentally suitable for the controlling of a web spreading system.

The fuzzy controller uses empirical knowledge as an information source and evaluates this knowledge about a controlling process. The controller shows a good transfer behavior and is characterized in this case by high robustness against parameter variations and changes of the controlled and error variables. This controller type has a minor control effectiveness in comparison with conventional controllers. In order to receive a sufficient control effectiveness, there must be a great database of empirical knowledge and pre-formulated rules. Furthermore suitable procedures for the fuzzyfication, the interference mechanism and the defuzzyfication have to be available as well as an interactive interface for the user to optimize the control behavior [8]. Inspecting these conditions, the experiences with fuzzy controllers show the problem of empirical knowledge sourcing. The procedures, the interactive interfaces and the development systems are matured for the conception of controllers. With the result, that the use of fuzzy controllers are recommended when sufficient empirical knowledge with high truth content is available.

The difference between neural, conventional or fuzzy controllers lies in the fact, that its coding with a specific solution procedure or an explicit problem solution knowledge is not necessary. The main component, the neural net, is able to process a specific problem without any analysis or declaration of his structure, without the programming of explicit rules and without the application of an inference mechanism. That means, that a thorough and complete analysis of the given controlling task is not necessary. Furthermore, the creation of a process model is not necessary and no extensive algorithms are needed. In addition, the number of the influence parameters on the control process can be chosen freely. This approves a high flexibility and supports the procedure of the controller optimization. Furthermore, in comparison to fuzzy controllers, the neural controllers have the advantage, that they do not need any pre-formulated systems of rules. They can be optimized by training of the neural net. However, a great extent of empirical knowledge is necessary for the training of the net, which can be easily generated from the operating status. Neural controllers have the disadvantage that on the one hand the learning-success of the training during the development is not predictable and on the other hand the physical reciprocity represented in the controller do not become recognizable.

Additional to this comparison in this research project both controller principles have been analyzed [7]. The results of this investigation emphasized, that the advantage of neural controllers, opposite to the fuzzy controllers, consists in a considerably smaller effort for the recording of operating states and for the recording of empirical profound knowledge. This advantage compensates the disadvantage of higher efforts for the conception and optimization of the neuronal net, opposite to the conception of fuzzy controller.

APPLICATION OF A NEURAL CONTROLLER FOR THE DUAL SPREADER

The realization of the control strategy on the basis of neuronal controllers is demonstrated at the example of a dual spreader. In this case, the explanations are based on the following development phases of control engineering and working steps:

preparatory phase
- task definition
- selection of the draft and simulation system

conception phase
- recording and structuring of the test data
- preprocessing of the test data
- analysis of suitable network topologies
- analysis of suitable learning algorithms

simulation phase
- simulation of the controlled system
- evaluation of the control effectiveness

application phase
- implementation of the controller
- inspection of the control effectiveness

Preparatory Phase

The task of the controller is based on the mentioned basics of the dual spreader and is limited by the slit gap adjustment. This arrangement is defined as the bacic component of the neural controller. It considers on the one hand the folding effect and on the other hand the carry out effect. For the basic component of the neural controller this means, that the defaulted width of the slit gap L_S as a command variable, the influence parameters of the construction R_2, R_3, L_1 and α as an error variable as well as the height of the roller curve H_2 as a manipulated variable are used. This basic component represents the draft and simulation basis for the development of the controller.

After a system comparative analysis [7], the "Stuttgarter Neuronale Netze Simulator" (SNNS) [9] was chosen for the draft and the simulation of the controller. SNNS consists of a simulator, a graphical user interface for the generation, visualization and modification of the neural nets (figure 7) and a compiler for the generation of huge nets from a net description language. The simulator manages the intern representation of the neural nets and carries out all operations for the simulation in the learning and working stage. It allows an efficient retention and manipulation of small and big nets. The graphical user interface represents the topology and the state of the net graphically. With the use of an integrated net editor it permits the construction and the modification of neural nets interactively. The Nessus-Compiler as a procedural programming language is employed for the description of the network topology. It translates the net modeling in an input file for the simulator, combines source files and previews in neuronal nets and computes the layouts of the generated nets for the graphical user interface. The design of the SNNS supports a great number of neural models and enables the simulation of every net that can be represented as a directed and weighted graph.

Conception Phase

The controller's conception needs a great operating data extent for the training, validating and testing of selected network topologies. Experience show, that oriented at these analysis aims it is purposeful to structure the available data in data sets. Accordingly, 300 data sets were used for the training and 100 for the validation and test set and arranged as a database for the slit gap controlling.

When mathematical relationships can be formed between influence parameters the preprocessing of these data sets recommends reducing the number of the input variables of a neural net. For the examined basis component of the controller, the mathematical relationships of the idealized operating range can be used. The achieved result is, that the three input variables (L_S, L_1, α) are sufficient to determine the output variable H_2. The selection of a suitable network topology must be based on the respective problem.

The experiences show that so-called feedforward-nets on the basis of the multilayer-perceptrons are suitable for controlling tasks. The network topology consists (viz. figure 8) of an input layer, one or several hidden interlayer as well as an output layer. As a learning algorithm, the backpropmomentum-procedure was selected as a specific version of the backpropagation. On this basis, four different network topologies were examined for their learning-behavior and for their performance according to the layer-perceptron-principle with up to three interlayer. It resulted that already a three-staged net with an interlayer leads to a good training result with high performance. In a following optimization step, this three-staged network topology was optimized by variation of the neuron number and the weights in the interlayer. The optimization result is shown in figure 9. Therefore, a three-staged net with eight neurons in the interlayer is able to reach already the lowest error level.

The interpretation of this conception result shows, that this trained three staged network topology is able to control the required slit gap through changes of the roller curve height with influence parameter variations of the idealized operating range and of the wrap angle. A further development of the controller through addition of further disturbance signals, e.g. influence parameters of the material properties (friction behavior, moisture or permeability) or process parameters (web tension or web velocity) demands a new network topology and a new training for the optimization of the net.

Simulation Phase

The test of the neural controller was carried out for different dual spreader geometrical configurations through simulations of the controlled system. The geometrical configurations of the dual spreader (viz. figure 3) have been varied in accordance to practical specifications. The evaluation of the control effectiveness was measured by how much learning-steps and at which error level of the learning the defaulted slit gap could be stabilized. The simulation results show that neural controllers are able to solve controlling tasks of web spreading with high control effectiveness at acceptable conception and simulation effort.

For the measurement of the control effectiveness extended nets are supposed to be examined, with addition of material properties and process parameters. At this point, it is the aim to work with a raised number of input variables. Next to the geometrical manipulated variable H_2, the tension is to be approved as a manipulated variable.

Application Phase

After the simulation phase is finished, the implementation and test of the developed neural controller are planned in a machine.

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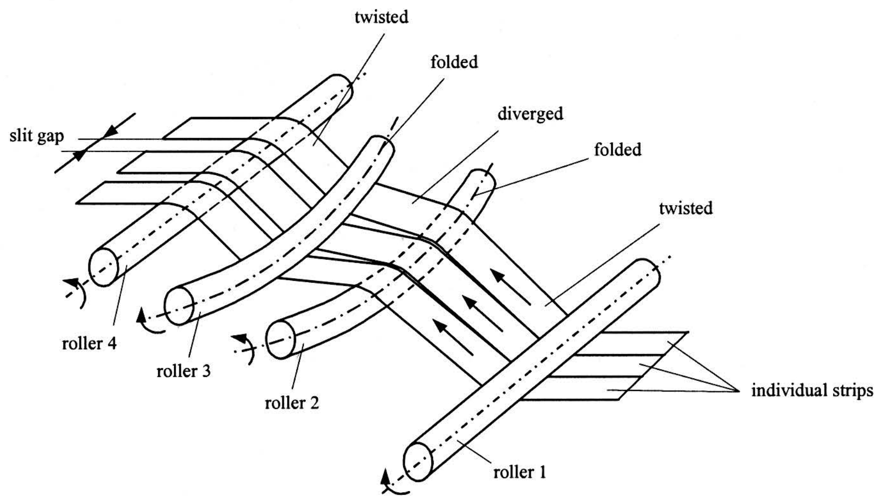


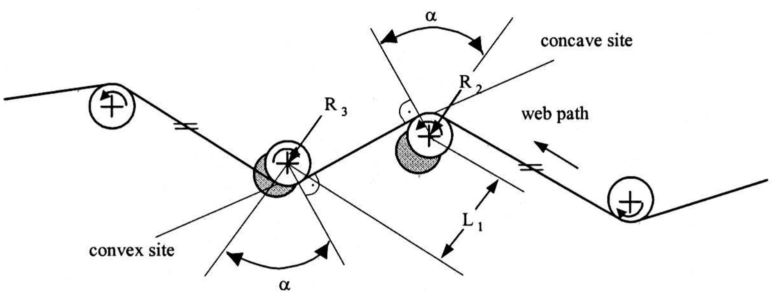


Fig. 1 Geometric requests of a dual spreader

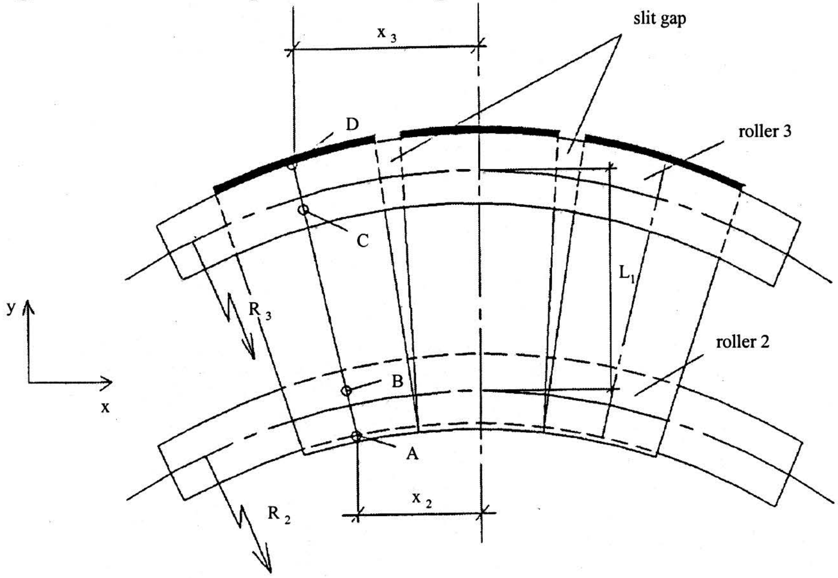
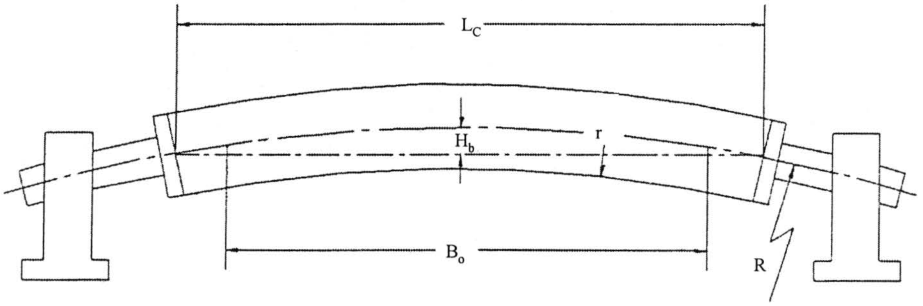


Fig. 2 Web path free of bending moments (dual spreader)



roller radius: $r = 95$ mm
web width: $B_o = 3600$ mm
roller length: $L_c = 3640$ mm
adjustable curve height: $H_b = 0 - 50$ mm
maximum distance of rollers: $L_1 = 380$ mm

Fig. 3 Dimension for the example of a dual spreader

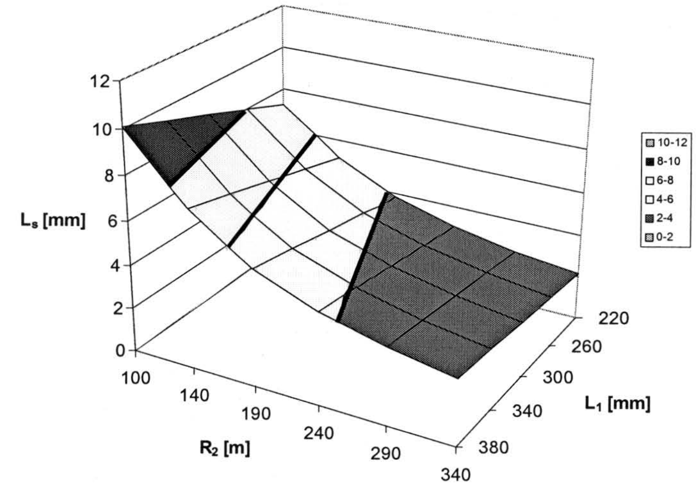


Fig. 4 Idealized operating range of a dual spreader

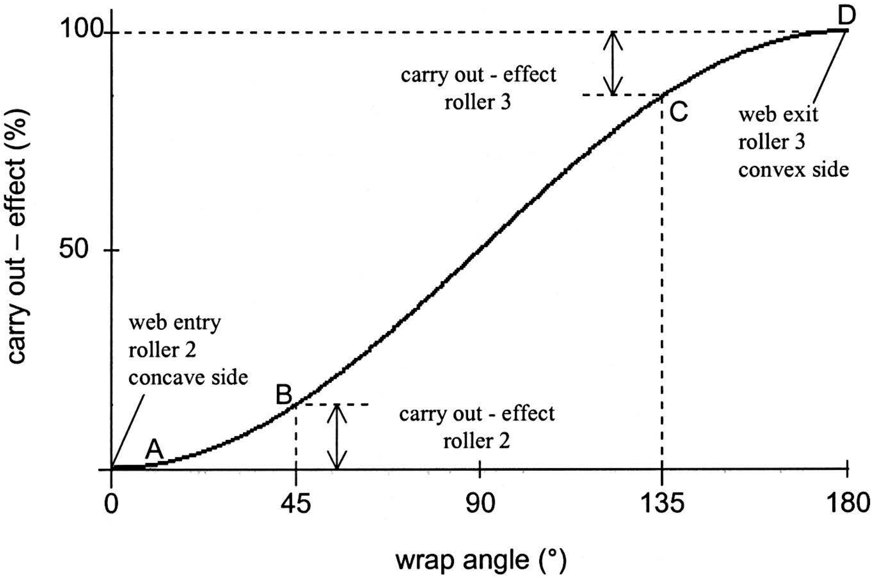


Fig. 5 Carry out - effect of a dual spreader

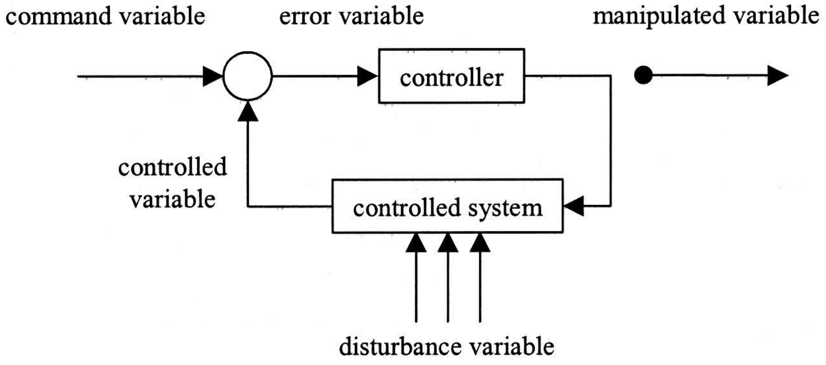


Fig. 6 Reference model of the automatic control loop

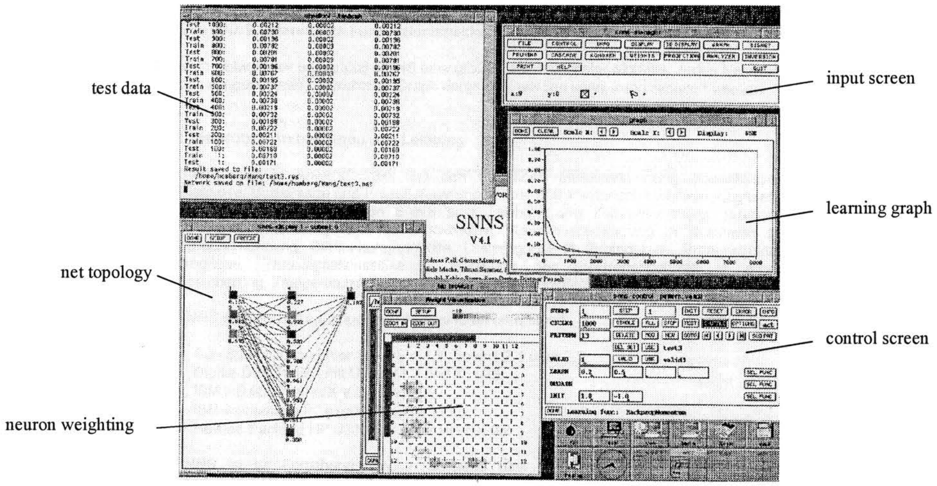


Fig. 7 Elements of the SNNS graphical user interface

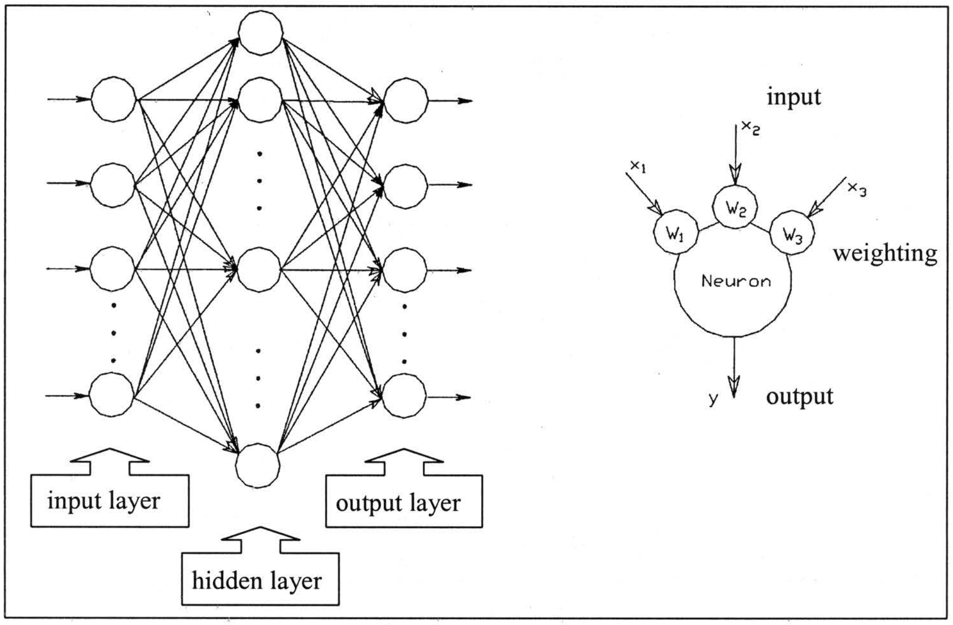


Fig. 8 Net topology of a feed-forward-net (multilayer-perceptron)

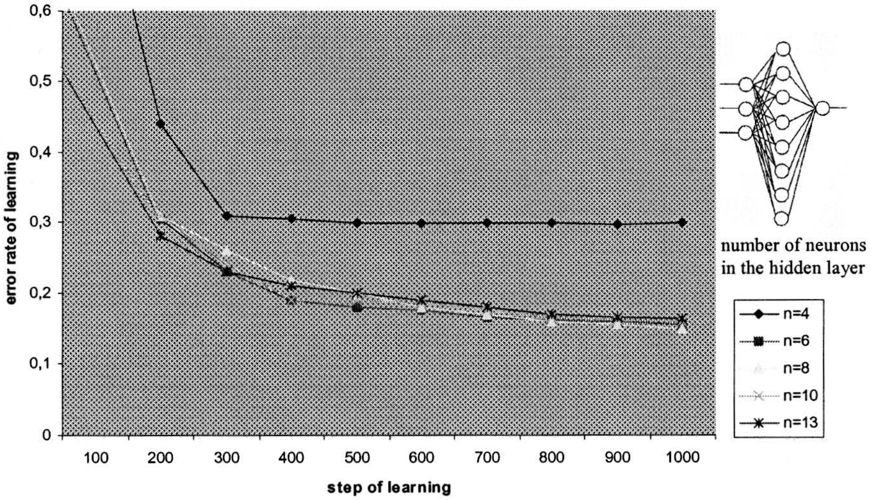


Fig. 9 Training result of a multiplayer-perceptron-net with the backpropmomentum-procedure as training algorithm

A Regulation Concept for Web Spreading Equipment in Web Processing Machines on the Basis of Neural Networks

E. G. Welp, D. Wang, and A. Kleinert – Ruhr-Universitaet Bochum, Germany

Name & Affiliation	Question
D. Carlson – 3M Corporation	If I understand correctly, you are adjusting the angles of the bowed rollers to control the distance between the strips. Can you clarify first how you measure that, what the feedback is for the control because you have multiple strips and secondly can you clarify the training; how you develop the data to apply to the training process.
Name & Affiliation	**Answer**
A. Kleinert – Ruhr-Universitaet Bochum	It is really difficult to measure the web angle in the real process. We have used this equation to calculate, the slit gap. The carry out affect, there will be an equation as well which is well known, and we created a great amount of data with this equation. With this data, we were sure that we had the influence parameters exactly described. So, the next step was we gave the neural net only this data and as a error variable we compared with alpha. So the net does not know how alpha reacts, and then we compared it with this equation.
Name & Affiliation	**Question**
D. Pfeiffer – JDP Innovations	You have introduced us to a new term "defuzzification" in this talk. I wondered if you would explain further as to when this is accomplished and who does it?
Name & Affiliation	**Answer**
A. Kleinert – Ruhr-Universitaet Bochum	Defuzzification, fuzzy data, you have an interference mechanism in this process. After you have done the waiting for the different kinds of ranges, you need, after the calculations, defuzzification.
Name & Affiliation	**Comment and Question**
P. Pagilla – OSU	Defuzzification is just the inverse problem. You get a fuzzy set of rules and you want to get your results back after you do some analysis on that fuzzy set of rules. I think that is what he is trying to say. How do you know that you are sure the model is a static model and what are you changing here, R1, R3, L1 following on Dan's question? Are you changing L1, R1, R2, R3?

Name & Affiliation	Answer
A. Kleinert – Ruhr-Universitaet Bochum	In response to the second question; the three influence parameters are related by the shown equation. We have used only one of them as a manipulated variable. In production you would use R2 or R3 because L1 is fixed by the construction principle and is not easily changed. In answer to the first question; this is a geometric criteria so we know that this is static.