REVIEW

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Weaving Machinery and Its Related Technologies

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Abstract

Published research work concerning weaving machinery and its related technologies in the period between 1990 and 2005 are surveyed in this review. Air-jet looms have been introduced to a lot of weaving mills widely and rapidly in spite of their uncertainness of weft running. Thus researchers concerned with weaving machines have paid a great interest in air-jet weft insertion technology. Developments of measuring devices, photographic technology, control devices, and personal computers brought active research work in the fields of the air jet weft insertion: especially spreads of personal computers have facilitated to solve almost all types of equations of motion. In consequence, numerical simulations for weaving machines have been easily performed including weft insertion, warp tension, mechanism design for loom and so on.

Key Words: Loom, Weaving Machine, Weft insertion, Shedding, Beat-up

1. Introduction

The term "weaving machine" took the place of the term "loom" during the last two decades because the weaving machine has been developed in both highly precise and high speed operation. Furthermore, mechatronics technology has been also introduced in textile industries. Especially air-jet looms have been spread to a lot of weaving mills widely and rapidly because of its great advantages in productivity. Thus recent research work concerning weaving machine and its related technologies will be reported in this article. I have surveyed published research work in the period between 1990 and 2005 mainly in the representative research journals such as "Journal of Textile Engineering" and its predecessor journal "Journal of the Textile Machinery Society of Japan (Sen-i Kikai Gakkaishi)" and "Textile Research Journal".

2. Weft insertion

2. 1 Air jet weft insertion

In air-jet weft insertion, the weft yarn is moved by the frictional drag between the air stream and the yarn surface. Air flow in an air jet loom is complicated, i.e., it is unsteady, turbulent, and can be compressible or incompressible flow depending on its velocity. Furthermore, air drag force is affected by air flow. Thus weft insertion depends on the flow characteristics and properties of the weft yarn. Many researchers have investigated air flow and/or air drag force in the weft insertion process.

Following the previous research work about fluctuation of yarn tension, which was examined experimentally and analytically [1] and measurement of the characteristics of jets injected from sub-nozzles [2, 3], Yoshida et al. [4] investigated velocity characteristics of weft yarn during weft insertion in an air-jet loom experimentally. Velocities at an intermediate point between a main-nozzle and a gripper were measured with a laser-Doppler velocimeter which was designed for fluids. In addition, mean velocities of yarn at the leading end and yarn-tension fluctuations were measured and compared with each other. From those results it was found that transient velocity fluctuation which had significant relation to tension fluctuation took place at both the start and the end stages of the weft insertion. Especially at the end stage of insertion, velocity fluctuation was affected by looseness of the propelling yarn.

Adanur and Mohamed [5] investigated a qualitative analysis of air flow in a single nozzle air-jet insertion. Dynamic air velocity measurements showed that the air velocity depended on two variables, i.e., distance and time. It increased with time (distance constant) and decreased with distance from the nozzle. Adanur and Mohamed [6] also analyzed yarn tension during air-jet filling insertion both

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experimentally and numerically for drum and loop storage systems. The model for drum storage showed that the yarn tension depended on the frictional force between the drum surface and the yarn, the mass linear density of the yarn, and the unwinding speed. A set-up was developed for air friction coefficient measurements, and friction coefficients for two different yarns were determined.

Furthermore, Adanur and Mohamed [7, 8] analyzed dynamics of air-jet filling insertion both experimentally and numerically on unsteady-state running conditions. Numerical models for both loop- and drum-storage systems were developed to investigate the air-jet filling insertion process. The flight of the yarn in an air jet was a complex dynamic problem, which was affected by many factors, such as air velocity and yarn characteristics, as well as the yarn-storage and yarn-feeding systems. Numerical simulation showed that the yarn velocity increased with increasing air/yarn frictional force and with decreasing yarn tension. A loop-storage system gave higher yarn velocities than a drum-storage system. However, there was better control of the yarn with drum storage than with loop storage. Since the filling insertion with an air jet was not positively controlled, pick-to-pick variations occurred. Statistical analysis of experimental data was, therefore, performed.

Adanur and Bakhtiyarov [9] developed a separated flow model to simulate air flow in a single nozzle air-jet filling insertion through the guide channel, which is half open and corrugated. Subsonic air flow in the guide channel was investigated as a simplified model of air flow in a single nozzle air-jet filling insertion system. The drag coefficient in the guide channel and propelling force acting on the yarn were calculated. Numerical simulation of drag coefficient and propelling force were in good agreement with experimental data obtained on the same conditions.

Adanur et al. [10, 11] measured air pressure and air velocity on an air-jet filling insertion simulator with tube and profile reed. Then, the filling yarn insertion time was measured on the air-jet filling insertion simulator with the profile reed, and yarn velocity was calculated. The effects of supply pressure and running speed on filling insertion time were analyzed for the yarns with different yarn properties, such as yarn hairiness, twist, ply, yarn count, and yarn manufacturing system. The results showed that most of the yarn properties have an effect on yarn insertion behavior.

Ishida and Okajima [12–16] measured static pressures on the walls of the main nozzle and analyzed flow velocity changes in the nozzle tube by changing air tank pressures and acceleration tube lengths. The flow might reach a critical condition of Mach 1 at two positions, the needle tip and the acceleration tube exit. Increased tank pressure brought about the critical throat condition at these two positions, thus the flow in the nozzle was able to be completely defined. The tank pressure P_T to bring the needle tip to the critical condition depended on the acceleration tube length, and P_T was higher for longer acceleration tubes. The P_T value required to bring the acceleration tube exit to the critical condition is nearly constant regardless of acceleration tube length. For the nozzle used in this experiment, tank pressure was about 4 kgf/cm^2. The jet-flow characteristics under tank pressures ranging from 2 to 6 kgf/cm^2 were studied to obtain basic data for an optimal design of the main nozzle in an air-jet loom. Furthermore, wefts were actually inserted in the nozzle and weft traction forces were measured. Axial changes of the nozzle jet speed and jet diameter below the tank pressure at which choking arises at the exit of the acceleration tube were largely different from those above that tank pressure. Choking arose within the upstream region in the acceleration tube (Mach 1), and the Mach number at the tube exit exceeded 1. When this happened, expansion waves occurred owing to under expansion, and the oscillation of compression and expansion waves was able to be seen in the downstream region. Therefore, the weft drag force, which represented the weft-flying property in a nozzle, increased in proportion to tank pressure P_T. But when the flow was choking at the exit of the acceleration tube, the weft drag force became nearly constant, even at higher tank pressures.

Iwaki et al. [17] discussed the yarn tension mechanism in nozzles both numerically and experimentally. Air flow rate in some kinds of nozzles were measured experimentally. The drag force acting on the yarns with different yarn structure and yarn count was measured. The yarn tension obtained was compared with the value calculated from the drag coefficient based on Reynolds number.

Fukai [18] discussed flow characteristics in a weft acceleration tube of an air jet loom, when a compressed flow was given to a weft guide pipe of the model main nozzle. Flow in the weft acceleration pipe was measured with a hot-wire anemometer when the flow-rate ratio was changed stepwise. The flow-rate ratio was defined by the ratio of central flow rate to annular flow rate. When an appropriate nozzle-flow-rate ratio was applied to flow of the weft acceleration pipe, it was found that flow, effective to acceleration of weft, was generated under the conditions such as reduced velocity defect among the axis of the pipe and dampened turbulent flow in the pipe. These experimental results proved that a serial structured main nozzle (tandem nozzle) was useful for establishing steady flying behavior of weft.

On the other hand, it is of great significance to study and improve the performance of sub-nozzles used at air jet looms in order to save energy. Shintani et al. [19] measured and analyzed the velocity distribution of jet flow from currently-used sub-nozzles to make clear its characteristics. Velocity measurement was made for four sorts of commercial sub-nozzles with different outlet shapes, such as circular, porous, rectangular and elliptic shapes. It showed clearly that the decaying characteristics of jet from sub-nozzles did not depend on the outlet shapes and were similar to that of axisymmetric jet flow from a circular tube nozzle. Furthermore, because the jet angle changed with supplied air pressure, it should be necessary to adjust the set-up angle and position of the sub-nozzle according to the air pressure. They concluded that the porous sub-nozzle performed best among the four kinds of sub-nozzles. In the following study [20], they measured velocity distributions at the nozzle exit and positions of jet center with a hot-wire anemometer in order to examine the state of flow at the sub-nozzle exit. Effects of passage area and nozzle exit shape on the jet angle were elucidated. The results showed that stream-wise velocities reduced to be inversely proportional to the distance from the nozzle exit irrespective of passage area or nozzle exit shape. This decaying characteristic was similar to an axisymmetric jet flow from a circular nozzle. The jet angles were changed by exit velocity, passage area and nozzle exit shape.

Shintani et al. [21] investigated some new types of sub-nozzle as trial pieces and their characteristics of air-flow in order to reduce the electric power consumed in air jet looms. The trial sub-nozzles were ceramic, and the exit cross-sectional area was convergent in the flow direction to minimize a pressure loss, and a deflector was devised in a chamber of the sub-nozzle, for smoothly introducing upstream flow to an exit. The test results of the new sub-nozzles were good; that was the jet angle issued from the nozzle was constant, and the air-flow rate was successfully reduced by 20% on the looms with the new sub-nozzles.

An air jet loom equipped with a profile reed and sub-nozzles can weave wider fabrics at higher speed than other types. Understanding of the characteristics of air flow on the profile reed is essential for reducing electric power of air jet looms and improving the fabric quality. Shintani et al. [22] investigated the behavior of air flows leaking through the profile reed experimentally. Visualization of leakage flows behind the profile reed, was made employing Schlieren method using the carbonic acid gas, and measurement of velocity distributions of leakage flow behind the profile reed was carried out with a hot-wire anemometer. Visualization results revealed that the air leakage behind the profile reed depended on the count of reed. The velocity distribution indicated that two concentration regions of leakage flow behind the profile reed were located at the distances of 40 mm and 60 mm from sub-nozzle. Position of the leakage concentration region of 40 mm was changed in the vertical direction by varying space ratio of the profile reed. The position of centers and direction of the leakage flow behind the profile reed could be clearly recognized by comparing the mean velocity distributions with the visualization images.

A study on the characteristics of air flow and behavior of the weft yarn in the weft passage area of the profile reed during inserting the weft yarn is very important. Shintani and Okajima [23, 24] measured the velocity distributions of air flow issued from a sub-nozzle in the weft passage in detail with a hot-wire anemometer. The motion of a weft yarn in the weft passage was also observed by photography. The experimental results indicated that the shape of the lower jaw part of the profile reed affected positions of the maximum velocity of the air jet in a cross-section until the air jet ran into the bottom of the reed. When the front side of the profile reed was closed, the value of the maximum velocity in the weft passage was smaller than that under the normal condition because of an increase in flow leakage behind the profile reed. The position of the maximum velocity in the weft passage was found to coincide with the position of the maximum leakage from the profile reed. It was confirmed by photograph that a yarn tip was led through the weft passage by the jet issued from a sub-nozzle.

The textile manufacture is obliged to shift to a large variety and small quantity of production in order to correspond to consumer need and to develop high value added products. The improvement in efficiency of warp preparation and a quick determination of weaving conditions (air pressure and injection timing) was important to an air jet loom. Shintani and Okajima [25] measured the air-drag coefficient of eight kinds of polyester textured multi-filament yarn in order to obtain basic data for determining quickly the weaving conditions in an air jet loom. And they investigated the factors which affected the air-drag coefficient of yarn and the following conclusions were obtained: measuring the diameter of polyester textured yarn used in the experiment, the diameter changed with the static loads and approached to about 1.8 times as large as the equivalent diameter calculated from yarn count. The air-drag coefficient of polyester textured yarn used in the experiment was explained as a function of the Reynolds number. Hatta et al. [27, 28] also investigated air drag force of yarn in jet closely.

Saving energy and expanding versatility are very important technical subjects for an air jet loom. Optimum weft-insertion conditions must be determined for each kind of weft yarn on the basis of the relationship between the airflow in the weft passage and the weft running behavior.

Shintani and Okajima [26] experimentally examined the relationship between weft-insertion conditions and weft insertion speed of polyester textured yarns by measurement of the weft tension with a benchmark-testing machine. On the other hand, the weft-insertion speed in an air jet loom was numerically calculated under the consideration that it is a function of the air velocity in the weft-yarn flight path. In the computations, the velocity distribution issued from a circular jet was applied to the equations of the weft motion in the air jet loom as the velocity distribution of the weft passage. From the results, the maximum weft tension increased linearly with an increase in the weft-insertion speed, and also the rate of increase in the weft tension was dependent on the yarn count. Furthermore, among all the weft-insertion conditions, which include the supply air pressure and air injection timing for the main nozzle and sub-nozzles, the main nozzle air pressure most strongly affected the weft-insertion speed. The computational results of weft-insertion speed were in good agreement with experiments using a 16.5 tex /96 f yarn, it was, therefore, confirmed that the method of numerical computation used for the motion of weft-yarn in an air jet loom was suitable.

In air jet loom, weft insertion time depends on the properties of the weft yarn. Vangheluwe [29] investigated the time needed to insert 50/50 polyester/cotton yarns with a nominal count of 20 tex on air-jet looms. A statistical approach was followed in order to relate weft insertion behavior to yarn properties. A model was developed using a back propagation neural network. Weft insertion behavior was related to yarn properties such as actual yarn count, diameter, hairiness, and irregularity. The results of the neural network were compared with those of multiple linear regression modeling. The effect of the parameters was illustrated using a factorial design on the neural network model. Vangheluwe and Puissant [30] proposed a control strategy using a Monte Carlo simulation in order to obtain a more constant arrival time over the bobbin. A mathematical model for weft insertion on an air jet loom was developed and the proposed control strategy showed good results.

In an air jet loom, compressed air is used for the insertion of the weft yarn. To make compressed air, much electric power is necessary; the power is two or three times higher than that used in other waving mechanical motions. From energy reduction point of view, Masuda et al. [31] developed a new apparatus which reduces the energy for the insertion. They assessed the ability of a new apparatus which assists mechanically the weft yarn insertion. It was found that the accelerating apparatus of the weft yarn (PDC-system) was markedly efficient for the insertion the weft yarn. The energy consumption of the compressed air was found to be reduced from 10 to 30 % with the supplementary apparatus. In the following work, Masuda et al. [32] investigated the effects of PDC working conditions on the tip velocity of weft yarn and the weft yarn tension. It was found that the flight state of the weft yarn was more easily controlled with the accelerating apparatus of the weft yarn.

The mechanical properties of the fabrics woven with an air jet loom are inferior to those of the fabrics woven with the rapier or the shuttle looms, although the same weaving yarns are used and the same textile weave is produced. Masuda et al. [33] investigated the change in the static mechanical properties of the weft yarns by weaving, and also they performed the dynamic mechanical tests on the woven weft polyester yarns. It was found that the storage modulus, *E*', observed below the glass transition temperature decreased and the maximum value of the loss modulus, *E*" also decreased by weaving.

Githaiga et al. [34] showed the dependence of the yarn speed on air velocity and yarn properties made the weft insertion process in air-jet weaving was complicated. The influence of the yarn properties as well as those of the production (spinning) parameters and fibre properties on the yarn insertion speed was investigated. A large number of cotton yarns were rotor spun from 20 different cotton fibre qualities, under different spinning parameters. The resulting yarns were systematically tested for various yarn properties and for yarn speed with an air-jet test instrument. In determining the statistical relationships, traditional statistical models and a back propagation neural network model was developed. Fibre quality and yarn production parameters were found to have significant influence on the weft yarn insertion speed. With respect to the yarn properties, high correlation coefficients were obtained between the experimental and the predicted values of the yarn speed.

Oh et al. [35] reported a numerical analysis of transonic flows in the axisymmetric backward-facing step main nozzle of an air jet loom. To obtain basic design data for the optimum main nozzle shape of an air jet loom and to predict transonic/supersonic internal flows, a characteristic-based, upwind flux difference-splitting method was used to solve the compressible Navier-Stokes equation.

Kayacan et al. [36] investigated the effects of yarn properties on weft yarn velocity along the tube and developed a weft insertion system in air jet weaving looms controlled using fuzzy logic. The effects of yarn linear density (tex) and value of twist coefficient on the change in weft yarn velocity were determined by the fuzzy logic system. Experimental data and expert knowledge used in the establishment of the fuzzy logic model and the construction of basic principles. The results obtained from the fuzzy logic model were compared with the experimental results.

Celik et al. [37] reported numerical simulation of the frictional drag between the air flow and the yarn surface in order to determine the motion of the yarn during an air jet weft insertion. Forces acting on the weft depend on time as well as the varying position of the weft during insertion. The mathematical model of the system was implemented with a worksheet, and the results were shown graphically. These simulated results were compared with those experimentally obtained for the weft yarn. Weft positions in the reed channel in relation to machine timing in terms of shaft degrees were measured by the stroboscope of the machine for each position. Weft speed was calculated from this measurement.

DeMeulemeester et al. [38] simulated the weft insertion process on an air jet looms as a possible solution to avoid costly weaving trials. A one-dimensional mathematical model of the yarn was developed in which the behavior of the yarn was described by Newton's Second Law. In order to solve a second-order differential equation, an explicit integration using Euler's method was chosen.

2. 2 Weft insertion by rapier loom

Rapier designed to control the yarn inserting motion from the start of the motion to its end. Washida et al. [39, 40] developed a servo-controlled weft yarn inserting mechanism designed to allow the characteristics of weft yarn inserting motion to be changed in order to study experimentally the effects of the characteristics of weft yarn inserting motion on the weft yarn insertion. In the experimental study, this mechanism was used in the rapier loom to insert weft yarn and the measurement of the weft yarn tension was performed. The results of the measurement showed that the weft yarn tension was significantly affected by the characteristics of weft yarn inserting motion. Then, to clarify the relationship between the weft yarn tension and the characteristics of weft yarn inserting motion, a weft yarn tension model was made for simulation. The results of the simulation were in good agreement with those of the experiment, providing theoretical explanation about the relationship between both. The above suggested that the servo-controlled weft yarn inserting mechanism is very useful for a rapier loom in terms of its allowing the weft yarn inserting motion to be changed properly according to the weft yarn to be used.

Washida et al. [41] conducted a further research work on a similar weft inserting mechanism to improve its control performance by incorporating a "Modified Repetitive Control with Corrected Dead Time". In the research process, the authors studied the specific method for incorporating the "modified repetitive control with corrected dead time" into the weft inserting mechanism, and investigated its control performance both through numerical simulation and experiment. The results of the simulation were in good agreement with those of the experiment, proving that the control method incorporated into the weft inserting mechanism, although not effective in improving its control performance in its transient-state period immediately after its start-up, was highly effective in providing it with excellent control performance during its subsequent steady-state period. With regard to improvements in the control performance of the weft inserting mechanism during its transient-state period, they presented specific measures for such improvements that were considered to be feasible and confirmed their effects through the simulation.

In rapier filling insertion by tip-transfer between two half-width rapiers, the filling clamps may be operated either positively or negatively at a transfer. Dawson et al [42] observed the trajectories of the transfer point on the giver and the clamping point on the taker rapier for both cases. With positively operated clamps, these trajectories are tangential, confirming that a filling velocity change at the transfer can be avoided. Negatively operating systems entailed an overlap of the trajectories and a filling velocity change at the transfer. A simple model of these operations gave an estimate of the velocity change at the transfer. For the two looms observed, this velocity change had a lower bound of about 20% of the maximum filling velocity.

2. 3 Other inserting way

Lappage [43, 44] investigated end breaks of eight kinds of singles yarn in both spinning and weaving process. He identified the end breakes by their causes and recorded them while plain weave was woven. End breaks were found to be due to failed splices, abrasion failure and thin places. The incidence of thin-place breaks was found to increase with increasing irregularity (CV%) of the yarn, and as the linear density of the yarn decreased. The most significant cause that affected the yarn count limit for acceptable weavability was the thin-place end breakage rate. And the thin-place end breakage depended on the evenness of the yarn. It was shown how to predict the thin-place end breakage rate from the yarn, fabric and loom parameters.

Wasiak et al. [45] estimated the influence of the settings of loom picking mechanism on the value and the distribution of weft take-up in woven fabrics. They used the NISSAN LW 551 water jet loom and the PICANOL OMNI air jet loom. In order to achieve a weft take-up distribution as good as possible and thereby a uniform woven fabric structure, with the use of a pneumatic loom, the best solution was to use high air pressure in the crimp removal jet or low air pressure in the sub nozzles; with the use of a hydraulic loom the most advantageous solution was to set a great water portion volume.

Mirjalili [46] attempted using electromagnetic force in weft insertion and built a laboratory model, which was able to launch the projectile at the speed of 20m/s. However only 6 m/s projectile speeds were achieved in the experiments.

Chikaoka et al [47] developed the check up system for the picking mechanism on water jet looms. This system caught the signal of water jet pressure with a pressure sensor, and detected the open-close of a clamper with a clamper sensor respectively, and measured such values as water jet pressure, jetting angle and flight start angle of weft yarn etc. As these measured results, this system was able to find the best condition of picking mechanism for weaving. This system was available for preventive maintenance of picking mechanism and contributed to decrease loom stoppage and poor condition of weft running. Thus it resulted in improvement of flexible manufacturing.

3. Beating

It is important to analyze and design beat-up mechanism for improving performance of weaving machines.

Dao et al [48] developed a dynamic analysis method for the beat-up process. Predictions of beat-up force and warp tension response during beat-up were made by setting up a weaving model under the dynamic conditions. Weaving machine and fabric parameters, static and kinematic coefficient and index of friction between the warp and filling yarns, total harness lift, shedding timing, back rest position, basic warp tension, and loom speed were taken into account in predicting beat-up force and warp tension.

Bullerwell and Mohamed [49] investigated the beat-up force on a water jet loom and the dynamic calibration of the force transducer. Experimental results showed that the loom speed and shed timing had no effect on beat-up force, while the pick spacing and linear density of the filling yarn had a considerable effect on the maximum beat-up force and the shape of the beat-up pulse. Using this measuring instrumentation, Shih et al. [50] measured the beat-up force on a needle loom. An additional measuring system using strain gauges verified the accuracy of the load washer. Both systems showed close agreement with measured beat-up force. Experimental results revealed that when the harnesses are level, beat-up force shows a linear relationship with pick spacing. Early shed timing causes an increase in beat-up force. An earlier theoretical model for the beat-up dynamics was verified. Both simulated and experimental results showed good agreement with relation to warp tension, pick spacing, shed timing and loom speed.

Wang and Sun [51] used CAD/CAE tools in order to study different kinds of beat-up mechanisms, including the 4-link and 6-link systems and the conjugate-cam mechanism, then those characteristics were compared. They analyzed the effect of geometric parameters on the motion characteristics of the sley.

He et al. [52] measured the fluctuation of the cloth fell point during weaving on the running air-jet loom. They used an oblique scanning method with an image scanner to capture the fabric surface image, and they also proposed a fluctuation index of woven fabric in the cloth fell as an evaluation parameter for stable beating-up motion during weaving on the basis of the numerical analysis of the cloth structure formation process. He et al. [53] also investigated the influence of weaving conditions on the surface texture of woven fabric estimated using image processing analysis and Fourier transform. They also investigated the relationship between the cloth fell fluctuation and reed mark behavior with theoretical interpretation in terms of cloth structure formation process.

In high speed weaving, it is important to keep weaving continuously in order to obtain even fabrics. Chen [54] discussed the characteristics of cloth formation in weaving in terms of continuous weaving, the concept of balanced weaving was put forward, and an equation of balanced weaving was then established for analyzing the response of the weaving process to disturbances of various kinds. On the basis of the analysis of beat-up resistance and weft yarn bouncing back, the cloth formation area was defined as an indicator of the weaving conditions.

Naoi et al. [55] introduced DLC (Diamond-Like-Carbon) coating technology to the reed dents in order to improve their wearing durability used for jet looms. The DLC coated reed wire exceeds 2000 in micro Vickers hardness (Load 50gf (0.49N)). In the accelerated wearing test, the non-coated reed wire showed flaws caused by friction with the yarn only 3 minutes after the test started. On the other hand, a vague flaw was observed 500 minutes after the wearing test started in the reed wire partially coated with DLC at the portion that realized the hardest friction by the yarn.

4. Shedding

Loom operation is constrained by the need to align the front shed boundary, the filling insertion element trajectry, and any insertion element guides within the working width. Dawson [56] investigated the loom timings of shuttle loom in order to align these parameters. An earlier analysis of these constraints was extended to cover the use of a raceboard as an insertion element guide. The deviations from the ideal configuration for insertion element guidance by a raceboard were analyzed for the general case, and then this analysis was applied to the shuttle loom. The results suggested that warp shuttle interference was able to play an essential part in enabling shuttle alignment requirements to be met when early shed-change timings were used. Dawson [57] investigated movements of the front shed boundary constrained on filling-insertion timings. These movements, which entail changes in shed shape, were determined by sley drive and shedding mechanism characteristics and by the shed-change timing. Shed shape was able to be specified by two angles whose variations with timing defined the characteristic that depicted the form of the whole sequence of shed shapes occurring during the loom cycle. Differences between such sequences of shed shapes were shown particularly clearly by this characteristic. The main forms of the shed-shape sequence, showing the effects of both sley and shedding dwells and of shed-change timings were illustrated. Examples of shed-shape-dependent constraints on timings were considered in conjunction with relevant shed-shape characteristics, and their implications were discussed. Dawson [58] extended the analysis of these constraints to cover guides inside the front shed. Additional constraints were imposed by the need to fully utilized reed height and to avoid guide penetration of the top warp sheet. The relation between shed accessibility to guides and reed orientation for the given shape of a shed of maximum extent was examined over the range of a shed accessibility parameter, thus covering both gripper projectile and rapier loom values. The parameter was sensitive to reed orientation: the quarter of its range in which the parameter lied was able to determine orientation to within a few degrees.

Recep et al. [59] introduced mechanism models for rotary dobby, crank and cam shedding motions, then equations governing heald frame motion were derived. Heald frame motion curves were obtained and compared with each other. It was shown that higher maximum velocity/acceleration of heald frame, as well as a longer approximate heald frame dwell, was generated by the rotary dobby rather than the crank or cam shedding motions owing to the intermittent nature of the motion of rotary dobby shaft.

It has become important to understand dynamic properties of moving parts of the loom with increasing speed of a jet loom. There is no information, however, on the heald vibration generated in the shedding motion of loom. Kinari et al. [60] investigated natural frequencies of the transverse vibration for healds by means of impulsive resonance. Frequency resonances were obtained for ten kinds of commercial flat healds that differed in their length, thickness or material with an impact hammer equipped with a load sensor and a laser displacement sensor system. The natural frequency of flat heald was able to be roughly estimated on the assumption that it has a uniform rectangular cross section. It was also found that the first natural frequency of the transverse vibration for the flat heald supported on its both ends became slightly higher than its actual driving speed.

The noise in weaving mills has been very large with increasing speed of jet looms. The main source of this noise was healds vibration generated in the shedding motion of the loom. It was desired to reduce the heald vibration in view of both the labor conditions and quality of produced fabrics. Kinari [61] summarized the research results of the Studying Group for Weaving Machine, Textile Machinery Society of Japan about heald frames equipped with bar magnets constructed on trial in order to reduce the heald vibration. The noise level was measured and heald motion was also observed at the same time by means of high speed video-camera system. It was found that the disorder of the heald motion during shedding motion decreased by equipment of bar magnets with the heald frames. Then, the sound heard by the human ears seemed reduced, but there was a little difference in the noise level measured by the noise-level meter. In the following report, therefore, Kinari et al. [62] arranged the high response sound measuring system in order to obtain the time chart of sound pressure level caused by healds during shedding motion. High-speed video-camera was also used in order to observe the healds motion. It was clarified that the noise was significantly connected with healds motion during shedding motion. Large sound occurred in two cases: when healds collided with the heald bar vertically near the upper dead point of shedding motion and when healds collided at random by rebounds around the lower dead point of shedding motion. Miyashita et al. [63] investigated frequency characteristic of noise caused by shedding motion using a Short Time Fourier Transform in order to relate the sound to the heald motion in a period of shedding motion. Power spectrum of sound showed a feature near the upper dead point of shedding motion when healds collided the heald bar. Superposing sound pressure signals during several periods of shedding motion, some peaks of power spectrum were emphasized near the upper dead point of shedding motion.

Mirjalili [64] simulated warp tension variation in a weaving machine using equations of motion. Differential equation system was formed and solved by numerical method. Calculated results for warp tension and back rail oscillation were compared with experimental results measured by projectile loom driven at 240rpm.

5. Other technologies

Blanchonette [65] measured the tension in weaving 25 tex singles worsted wool yarns with a commercial on-line tension measuring device. The maximum rate of tension change in warp yarns was 35 to 45 N/s (at beat-up) and in weft yarns 60 to 1000 N/s depending on the system of weft insertion. Weft yarn failure rates were predicted from measured weft tensions and Uster Tensojet results. Clinging of warp yarns increased the average tension by up to 20% for a plain weave.

Set marks in woven fabrics occur when a loom is stopped and restarted. They can be classified by human visual inspection. Vangheluwe et al. [66] proposed an objective way of measuring set marks by using image analysis. During weaving, warp yarns are subjected to dynamic loading. Vangheluwe [67] presented a test method for simulating the relaxation and the inverse relaxation of yarn during a loom stop. In order to analyze the cloth fell displacement of twenty different fabrics, Vangheluwe and Kiekens [68] measured the cloth fell displacement during relaxation of fabric-yarn combinations on a tensile tester. And then, Vangheluwe and Kiekens [69] proposed a model for calculating relaxation behavior after dynamic loading of fabric and warp yarns. The model was based on fitting the parameters of an extended nonlinear Maxwell model to experimental data using nonlinear regression. Combining the models for fabric and warp yarns was able to yield the viscoelastic behavior of the fabric-yarn combination, as well as the cloth fell displacement during the relaxation period. Using this model, Vangheluwe and Kiekens [70] numerically simulated the procedures to avoid set marks in weaving cased by warp relaxation.

Ayala and Govindaraj [71] proposed a method by which set marks in a fabric was able to be assessed by fast Fourier transform. Statistical studies validated the results obtained with the FFT analysis and established the influence of different stoppage times on the degree of set marks formed on the fabric.

Kovacevic et al. [72] measured the braking force of warp yarns taken per segments on the loom using three weaves from the same warp on different looms. Samples from the warp were taken in order to simulate the deformation of warp yarn.

The economic viability of a weaving mill is significantly influenced by its efficiency in eliminating fabric faults. Textile faults have traditionally been detected by human visual inspection, but it is time consuming and does not achieve a high degree of accuracy. Lin [73] evaluated the efficiency and accuracy of a way to detect the weaving density of fabric. Three basic fabrics weave structures - plain, twill, and satin - were evaluated using a co-occurrence-based method: this method was used to process image feature extraction and obtain a feature parameter. It consisted of contrast measurements involving sixty-four spatial displacements and two directions of fabric images used for calculation. The calculation precision for the plain weave was better than that for the twill and satin weaves. Conci and Pronca [74] developed a simple system designed for fabric inspection and showed its efficiency in detecting twelve kinds of common defects.

Seyam and El-Shiekh [75–80] studied properties of fabrics woven from regular warp yarns and filling yarns with periodic mass variation in terms of weavability limit parameters. They derived theoretical maximum weavability relationships of fabrics woven from regular warp ends and variable thickness filling yarns by means of developing a local geometry where the thick filling place was interlaced with warp ends and where warp yarn was interlaced with thick and thin filling yarns.

Yao et al. [81] investigated the predictability of the warp breakage rate from a sizing yarn quality index using a feed-forward back-propagation network in an artificial neural network system. An eight-quality index (size add-on, abrasion resistance, abrasion resistance irregularity, hairiness beyond 3 mm, breaking strength, breaking strength irregularity, breaking elongation, and breaking elongation irregularity) and warp breakage rates were rated on the controlled conditions. A good correlation between predicted and actual warp breakage rates indicated that warp breakage rates was able to be predicted by neural networks. A model with a single sigmoid hidden layer with four neurons was able to produce better predictions than the other models of this particular data set in the study.

Ishii et al. [82–84] developed weaving technology for multi-products, small-lot production. First, they developed a semi-automatic reed drawing-in machine using air jet system. Using air jet was not only to thread warp yarn to dents, but also to expand the interval between dents of a reed. Consequently, a fabric was not damaged by some injured dents, resulting in high quality. Next, they developed an automatic warp drawing-in machine for simultaneously drawing a lot of warp yarn through the eyes of healds and dents of a reed using air jet system. Consequently, warp drawing-in process was improved and became efficient and quick. Most of woolen textiles companies are interested in planning new merchandise. It is often requested to change warp density in order to prepare many textile samples. Finally, they developed a reed which had variable interval of dents in range of 7.1dents/in. to 8.3dents/in. Improved reed enabled not only to produce many textile samples easily and rapidly, but also to produce a new type textile in which the warp density was continuously changed.

6. Summary

Weaving machinery and its related technologies have been continuously studied and developed in those 15 years. Among the weaving machines air jet looms have great advantages in productivity, thus they have been introduced to a lot of weaving mills widely and rapidly in spite of some problems about the accuracy of weft insertion and the energy consumption. Many research work related to weft insertion using air jet were, therefore, reported in the research journals concerning the textile science and technology. According to development of measuring devices, photographic technology, control devices, and personal computers, numerical simulations as well as observations and measurements of weft insertion have been performed easily and actively. Now the problems in the weaving machinery and technology fields are solving to improve woven fabrics and supply high-quality products. Furthermore, in advanced countries development of environment-friendly technologies will become one of the most important targets as well as productivity and versatility in a near future.

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