Journal of Scientific & Industrial Research
Vol. 84, January 2025, pp. 17-23
DOI: 10.56042/jsir.v84i1.8727

Design of a New Washing Machine to Clean the Needle Bed of an Electronic Flat Knitting Machine

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Received 12 February 2024; revised 18 September 2024; accepted 10 November 2024

An electronic flat knitting machine is traditionally used for knitting pullovers and other outerwear garments. When a typical electronic flat knitting machine runs for a certain time, the needle bed is filled with dust and lubrication. In order to solve this problem, a new needle bed cleaning machine is designed and manufactured by R&D department of "NIT ORME" Co. located in Turkey. In this article, the introduction of the washing machine, of which the prototype is produced and patented, and some analyzes, such as; structural, fluid flow and vibration, performed during the design of the machine is presented. SoloidWorks, ANSYS-Structural and ANSYS-CFX are the commercial softwares used for the analyses. As a result of the prototype production, the needle bed of knitting machines is automatically washed and dried faster than similar products in a practical, easier and functional way. Additionally, the cleaning costs are reduced by 70% with the washing machine.

Keywords: Design and prototype, Electronic flat knitting machine, Manufacturing, Needle bed washing, Optimization

Introduction

Knitting machines are classified according to the thickness of the fabric they knit. This measure is expressed as "gauge (G)". Knitting machines produce fabric in thicknesses between 3G and 18G. The channel widths in the needle beds of the machines of these thicknesses vary between 0.5 – 2 mm and the average length of these needle beds is 1200 mm. Needle beds consist of 144 channels and many thin sections up to 864 channels. During knitting, these channels are filled by dust and hair produced by the yarn combines with the oil in the machine, resulting in slime (felt) and clogging of the channels. With this pollution, the movement of the needles is limited by getting stuck and it causes errors called "missed" in the knitted fabric (Fig. 1).

In order to clean the felted oil and remove dust in the channels of the needle bed, approximately 10000 needles in each channel must be removed one by one. For all these processes, at least two people can clean the needle beds of only one knitting machine in one day. It can be said that there is a serious financial loss, if the needle in each channel are lost, broken and not working properly when they are replaced during manual cleaning processes. During the assembly and disassembly of the needles in each channel during cleaning, knitting problems occur in the machines due to faulty alignment and the quality of the fabric deteriorates. In this case, a machine that cleans the needle beds is needed. This study introduces a new developed and designed needle bed washing machine.

It was shown that the causes of knitting machine stoppages may be; yarn breakages, set-off, machine cleaning and fabric roll cutting, yarn joining, needle breakages and oil problem. Machine cleaning mostly the needle bed cleaning occupied the 40.38% of the total stoppage time.[1] Hence, washing needle bed becomes a severe problem for the textile industry. Unfortunately, no scientific or technical study directly related to needle bed washing has been found in the literature. The few studies are generally on surface cleaning with water jet. Since a washing machine working with the water jet principle was designed in this study, articles on this subject were included in the literature research.

The working principle of a needle bed machine is actually the mentality of impinging the water to a surface with high velocity. With the impinging jets the impingement zone produces a normal impact that overcomes the initial adhesion force, causing fissures and reducing the attraction forces between the

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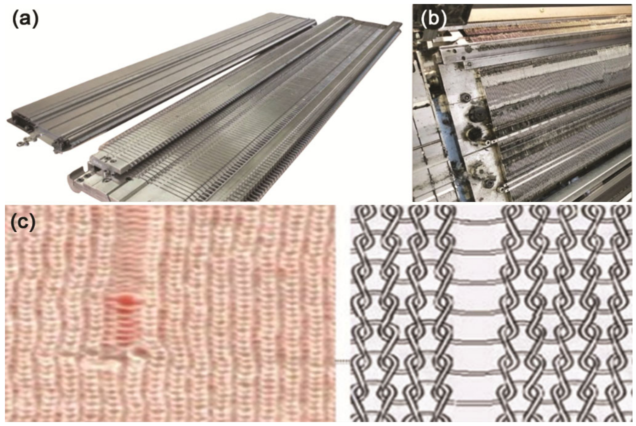

Fig. 1 — Needle bed and knitted fabric: (a) Clean needle bed, (b) Dirty needle bed, (c) kinks in the fabric knitted

contaminants and the surface. Particles, viscous fluids, or a combination of both might be considered impurities. The contaminants are then forced outward by the wall jet's radial forces, creating a clean surface.

Since 2012, quantitative models of the hydro-dynamics of the flow generated by a coherent liquid jet impinging on a flat vertical wall have been developed and combined with cleaning models to predict the removal of soil layers from such walls.[2,3] Landel and Wilson[4] reviewed the range of fluid mechanics phenomena involved in cleaning. They classified flows as either confined, such as those arising in piping and heat exchangers, or free surface flows, such as those generated by jets and sprays.

Ahmad *et al.*[5] carried out bauxite washing in the laboratory environment. Three techniques were studied in the laboratory: drum washing, water jet washing and ultrasonic washing. Various operating parameters were investigated for drum washing and water jet washing, including material retention time, drum rotation velocity, solids concentration, water jet spray time, pressure and height.

Gao *et al.*[6] demonstrated that hot washing technology has a low cost, but because of a rinse cycle, efficiency can be easily affected by the oil content in the clogs. The technology of cavitation water jets has good effects and the rinse cycle is 6 months, but the cost is high.

Wang and Khayat[7] theoretically investigated the flow of a planar liquid-free surface jet impinging on a porous layer, stress jump coefficient, and the depth of the porous layer on the super- and subcritical regions. Various mechanisms behind the numerically predicted behavior are explained.

Gomez *et al.*[8] showed that on the cooling of steel in motion that surface velocities of up to 1.6 m/s were obtained when cooling the moving surfaces. This value is far from real operating conditions where steel plates move between 2 and 22 m/s.

Marum *et al.*[9] prepared a one-dimensional mathematical model of a water jet coupled with Computational Fluid Dynamics (CFD) simulations. Using the data obtained from CFD simulations, the mathematical model was used to calculate the friction loss coefficients of the ejector components, to estimate the maximum efficiency point, and to limit the working area.

Köhler *et al.*[10] studied impinging jet cleaning process by means of various tests. The three most important industrial working parameters (nozzle diameter, pressure, and nozzle-to-surface distance) were varied during cleaning tests using a food-based model soil. Various boundary conditions pertaining to processes yielded distinct ideal outcomes, such as reducing the amount of time spent cleaning, the amount of fluid used, or the overall cost of cleaning.

Chee[11] examined three facets of jet behavior to facilitate the methodical design and optimization of clean-in-place systems. The radial flow zone form was predicted by existing models, and the flow patterns produced by the impingement of a coherent, turbulent, horizontal water jet on a flat, vertical target were compared and characterized as a benchmark.

As can be seen from the literature review, machines working with the principle of washing by spraying or impinging water at high velocity differ greatly according to their functions. In this study, a new washing machine was designed and prototyped to clean the needle bed in an electronic flat knitting machine. Before the introduction of the machine, brief feasibility research was made on the importance and necessity of the machine.

Pre-analysis of the Needle Bed Washing Machine

The R&D department performed some analyzes before the production. These can be listed as:

- ✓ All kinds of fluid scenarios of the machine were modeled with the ANSYS-CFX software in order to examine the deformation of the needle tips and the dangers of breaking and cracking during both water (impact) jet washing and air jet drying. The results were presented to the scientific world in an academic study.[12]
- ✓ In order to determine the loads that the needle can withstand, ANSYS-Structural analysis was performed.

- ✓ All finite element analyzes such as static, mechanical, fatigue-life, thermal, vibration on the virtual prototype of the machine to be designed were carried out in Solid Works.
- ✓ Appropriate software was prepared for PLC (Programmable Logical Controller) and HMI (Human-Machine Interface). Automation of the machine was provided by means of both predefined parameters and parameters that can be changed by the user.
- ✓ Weights for linear axis and slides were determined and appropriate designs were made. The power of the servo motor required to drive the linear axis was calculated.

Flow Analysis of the Impinging Nozzles

Now, it is time to briefly touch on some of the important results of the flow analysis. First of all, Computational Fluid Dynamics (CFD) analyzes were performed with the help of the ANSYS-CFX commercial software, which uses the finite element method. Since water impinging the entire needle bed means billions of nodes and elements which mean solution takes days or weeks. Therefore, a section of the needle bed was taken to create a solution domain. Velocity, pressure and force were found in the solutions based on the nozzle placement shown in Fig. 2.

Flow analysis was performed if the water coming out of the nozzle had a flow rate of 4.8 liters per minute. Since the flow is turbulent at the given flow rate, turbulence modeling has been done. The entrance where the nozzle velocity value is entered as the boundary condition, the outer walls of the needles is the wall that meets the non-slip condition; the lower part of the table is selected as the output. The velocity change obtained as a result of the modeling is given in Fig. 3a as colored contours, the vector representation of the velocity is given in Fig. 3b, and the streamlines are given in Fig. 3c. On the other hand, the values taken as output are pressure and momentum. The pressure formed in the washing machine is given in Fig. 3d.

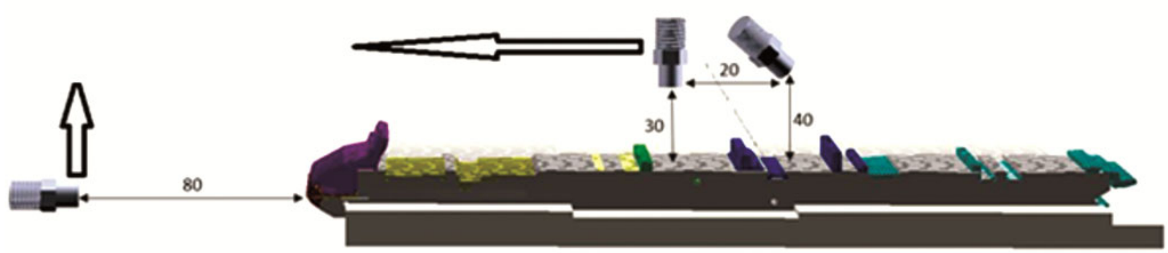

Fig. 2 — Physical model for CFD analysis

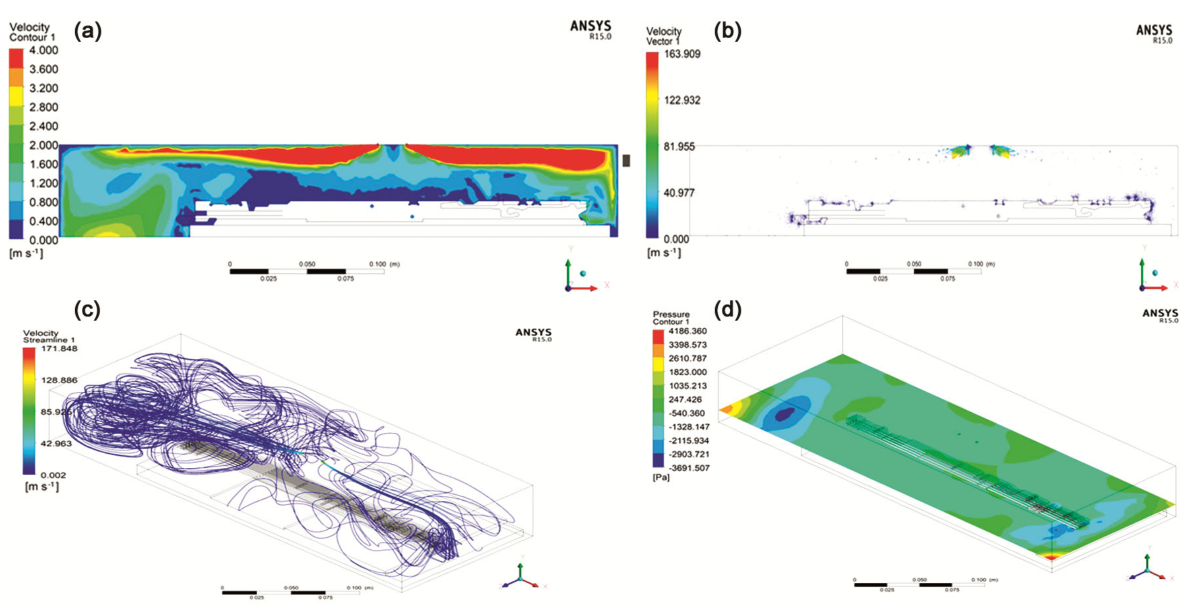

Fig. 3 — Results of the CFD analysis: (a) velocity contour, (b) velocity vector, (c) streamlines, (d) pressure contour

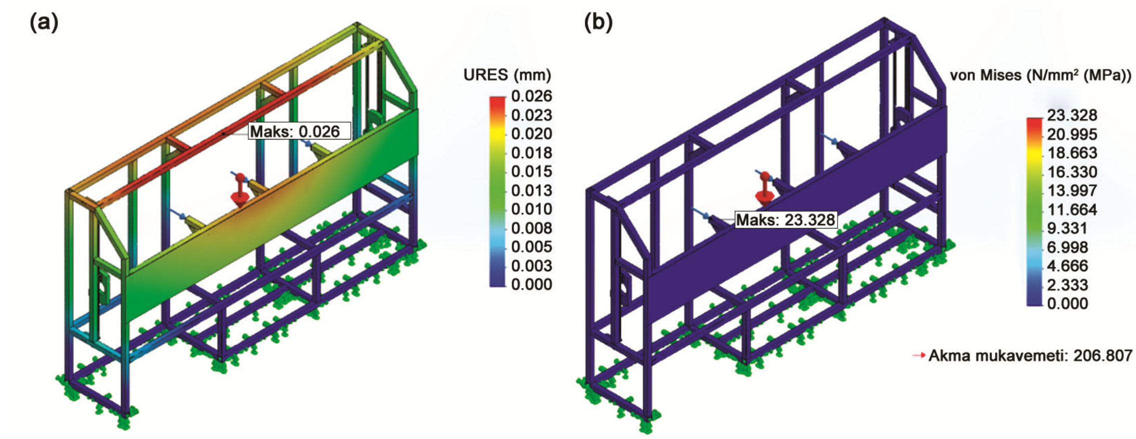

Fig. 4 — Some static analysis results: (a) Displacement, (b) von Mises stress

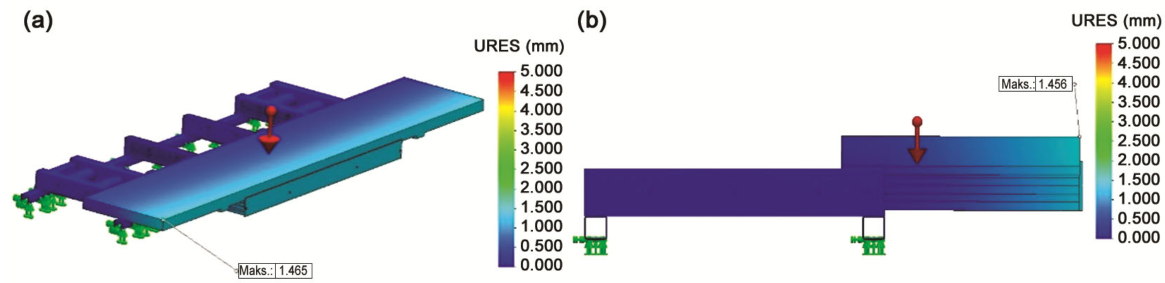

Fig. 5 — Loads affecting the conveyor (a) Displacement, (b) Force effects

It is seen that the water impinging the uneven geometry of the needle has the maximum value during the exit from the nozzle, not during the impingement. Since the uneven structure and smooth surface of the needle formed the stopping point, there was no excessive velocity reaction on the needle surface. However, the maximum effective velocity is close to the desired value in such machines.

Structural Analysis of Machine and Conveyor

Static analyses are performed by using ANSYS-Structural software which uses finite element methodology. Result of the static analysis of the washing machine is given in Fig. 4. The maximum displacement was calculated as 0.02 mm as a result of the forces acting on the chassis, the effect of the pressurized water at 80 bars sprayed from the nozzles and the forces acting due to the gravity of the machine's own components. The von Mises Stress distribution, also known as yield strength, presented in Fig. 4b shows us that the limit value is well below 206 MPa. In other words, no permanent deformation will occur due to the forces applied while the machine is running.

As a result of the static analysis performed on the conveyor system shown in Fig. 5, it was seen that the maximum displacement at 100 kg load will be 1.46 mm when the conveyor drawer is in the open position.

By the analysis made on the plate carrier mechanism; the maximum displacement was calculated as 0.071 mm at a load of 100 kg under the effect of gravity and when a pressure of 80 bars is applied simultaneously from 3 nozzles.

Filter Design

The analysis of the filter design is as shown in Fig. 6. In the case of 30 liters of water in the machine, the effect of gravity and its behavior under 16 bar internal pressure and 1 bar external atmospheric pressure were investigated and the maximum displacement was calculated as approximately 2 mm. This value will not cause permanent deformation.

As a result of the effects of 80 bar pressure applied to the entire needle plate section, the maximum displacement is 0.4 mm and there is no region exceeding the yield strength limit of 510 MPa. As a result of the effects of the 3.79 kg/cm^2 force obtained by calculating the surface impact effect on the entire needle plate section, there is no region exceeding the maximum displacement of 0.1 mm and the yield strength limit of 510 MPa, the 3.79 kg/cm^2 water created on the surface by the water hitting the surface with 80 bar pressure during washing. It has been predicted that such an effect will not create a permanent deformation.

Design and Manufacturing the Prototype

The new designed needle bed washing machine has two functions; automatic mode and manual mode, which are included in the standard loaded programs. In automatic mode, the cleaning process is started by selecting the length of the needle bed by the user via the touch screen on the control unit, and applying optimum time and pressures thanks to the pre-loaded algorithm, according to the length of the needle bed.

Deformation of the needles is prevented with the pressure settings automatically created in the software. In manual mode, the user can start or end the cleaning process by changing the pressure of the pressurized liquid in the machine, the movement speed on the D1 axis shown in Fig. 7, the durations of the foaming and drying functions and the duration of the total cleaning process, again via the touch screen. The duration of the cleaning process will be shorter than the current machines due to the pressurized liquid coming out of more than one nozzle, thus saving labor and time.

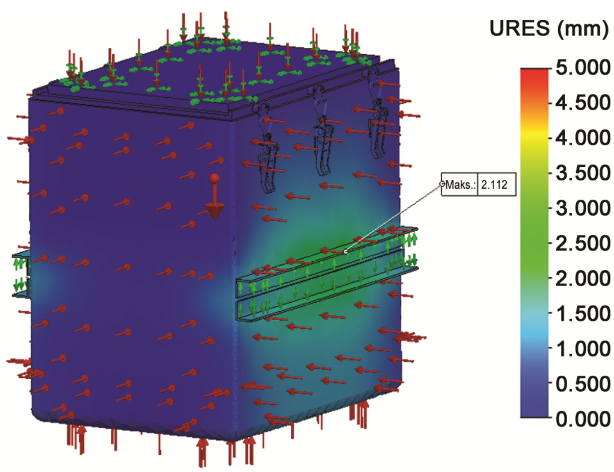

Fig. 6 — Design of filter

Thanks to the foaming function, after the pre-washing function of the needle bed, higher hygiene levels will be achieved compared to the current cleaning machines. The shampoo used dissolves in water and due to its basic structure, it enters between the dirt and the surfaces it touches and provides a sliding feature to the dirt, reducing the adhesion force to the surface and ensuring that they are separated from the surface by means of the pressurized liquid. Instead of using only water in the washing function, some corrosion preventive oil will be added and the needle bed will not come into direct contact with water, thus preventing unintentional corrosion due to oxidation.

With the drying function, the remaining liquid on the needle bed after washing will be removed from the surface, thus preventing possible corrosion attempts. Thanks to the filtering functions in total, namely washable sediment, anti-lime siliphos and granular active carbon in the liquid filtering function, the best filtration of the used water after the cleaning processes is ensured, both more efficient use of the washing liquid and extension of the machine's life.

The washing machine cleans dirt such as oil and yarn dust accumulated in the needle beds of electronic flat knitting machines as a result of use, and it consists of lower body (1), upper body (2), lower body cover (3), upper body cover (4), side cover (5), brush (6), control

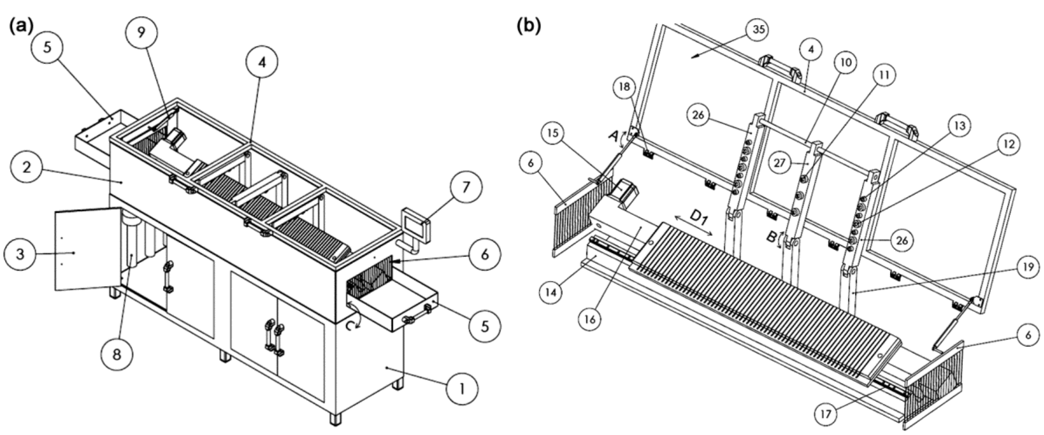

Fig. 7 — Schematic views of the new-designed machine: (a) top view, (b) open view

unit (7), liquid filter (8), shock absorber (9), station holding arm (10), pressurized liquid nozzle (11), foaming nozzle (12), air nozzle (13), linear axis bearing element (14), electric motor (15), linear axis (16), linear slide (17), hinge (18), station upper body connection element (19), needle (20), linear slide carriage (21), linear axis carriage (22), needle bed bearing element (23), needle bed connection apparatus (24), needle bed (25), drying and foaming station (26), pressurized liquid station (27), mounting bolt (28), needle channel (29), It includes pressurized liquid (30), shampoo foam (31), pressurized air (32), dirty liquid (33), upper body discharge hole (34) and transparent rigid plastic (35) parts.

The dimensions of the machine, whose mechanical design is made, are 2632 mm in width, 1552 mm in length, 808 mm in width as shown in Fig. 8, and needle plates with a total length of up to 1600 mm can be washed in the machine. The needle plate moves horizontally to the right, to the left and vertically up and down, and the nozzles positioning it fixedly are provided to scan the plate surface.

In the design of the machine, 304 quality stainless steel material was chosen to be used for the chassis and other body components due to its high corrosion resistance against water and at the same time its mechanically very durable structure, easy welding and easy availability in the market.

In the washing machine design, SH15 slide and carriage were chosen as linear slides for the slides to be used in the movement mechanism. In addition, the ball screw system was used to keep the motor dimensions small as the system to transmit the movement. A diameter of 16.5 pitch ball screw and a linear bearing to work on are selected. By calculating

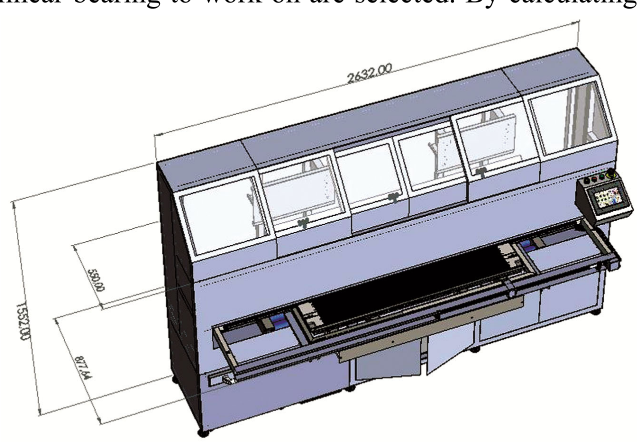

Fig. 8 — Sizes of the designed washing machine

the motor torque to be used according to the selected diameter 16, 5 pitch ball screw and the load to be lifted by the system;

$$F_t = \left[\frac{mh}{\pi d_2}\right] g = \frac{100\ (kg)\ 0.005\ (m)}{\pi\ 0.016\ (m)} 10 \left(\frac{m}{s^2}\right)$$

$$= 99.4\ N$$

$$M_T = \frac{F_t d}{2} = \frac{99.4\ (N) 0.016\ (m)}{2} = 0.79\ Nm$$

A step motor of 1.4 Nm on the Y axis and a step motor with a holding torque of 8.5 Nm on the Z axis, which can meet this torque value, are selected. Mechanism directions are as shown in Fig. 9.

A command is given from the control panel for the machine to fix the plate to be washed on the plate carrier movement mechanism and take the plate to the washing position. The plate carrier mechanism is brought to the position where it will be connected to the Z axis carrier trolleys with the help of the conveyor, the correct position of the plate carrier is detected by the limit sensors placed on the machine and the pneumatic locking mechanism fixes the plate carrier. The plate carrier mechanism moves upwards in the Z axis to go to the washing position. While going up, the gear part on the carrier car moves parallel to the ground until the rack gear on the path followed by the car. While the plate carrier mechanism goes up in the Z axis, the rack turns 90° on the gear and is mechanically turned to the vertical position. The positions during washing are shown in Fig. 10. After the plate carrier mechanism is perpendicular to the floor, it comes to its final position before the washing process starts.

The washing machine, whose prototype was produced and registered by the Turkish Patent Institute with the patent number *TR 2021 005473 B* and the name of "*Needle Bed Cleaning Machine in Vertical Position for Electronic Flat Knitting Machines*", is shown in Fig. 11.

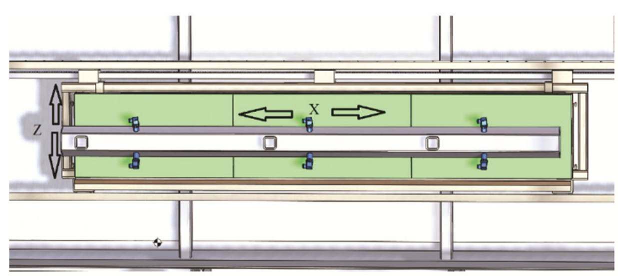

Fig. 9 — Washing directions

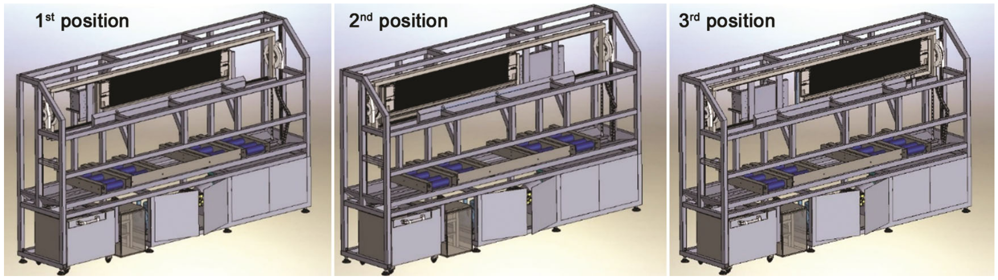

Fig. 10 — Washing process

Fig. 11 — Needle bed washing machine

Conclusions

In equivalent needle bed washing machines produced abroad, the entire surface is washed by providing the movement of a single nozzle in the X and Y axis with a linear axis, and this process takes 2 hours. At the same time, there is no dynamic pressure adjustment in these equivalent machines. This causes the deformation of the needles. By adding innovative ideas to several models of washing machines developed abroad in recent years, our company has created a new design by supporting the drying function and needle beds of different models. A washing machine with multiple nozzles, which calculates the optimum pressurized liquid pressure with analysis and experiments, and works in a way that does not damage the needle tips, has been designed. A method has been developed to indirectly measure the pollution of needle channels by using a force sensor.

Acknowledgements

This article is derived from the project titled "*Needle Bed Washing Machine Prototype Design and Implementation for Electronic Flat Knitting Machines*" numbered 7190814 and supported with 391,133.000 TL within the scope of TEYDEP 1507 SME R&D Support Program for one year starting from June 2020. We would like to thank TUBITAK for the financial support.

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