Electromechanical control for the step change of the stitch density of knitted fabric

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Abstract: Mechanical control of the modern small-diameter circular knitting machines is substituted elektromechanical control systems in this time. This contribution deals in project of the elektromechanical control for the step and continual change of the density of the knitted fabric. Stepping motor with electronic control was used for drive. This motor is acceptable for control of the density of the knitted fabric. There was made dynamic analysis of the mechanic system and was suggested adequate mechanism structure and stepping motor type with requested loading moment. Results will be employed for development small-diameter circular knitting machines in UNIPLET Trebic.

Keywords: small-diameter, density, knitting, stepping motor

Introduction

The worldwide trend in the development of small-diameter knitting machines is the application of electronics. The top manufacturers of knitting machines all over the world take advantage of the development of electronics in order to substitute mechanical systems, with the main aim to cut down the production costs of the mechanical sections, to simplify the actual designs of the individual assemblies and to lower the requirements upon the operation of the machine. Electronic control of knitting machines allows for a high variability of the manufactured products. The simplification of the actual knitting technology on the small-diameter knitting machines is of considerable importance as well, bringing important savings in the knitting mills.

These advantages of the electronic control of the knitting machines bring the respective problems to the foremost attention of all the manufacturers of small-diameter knitting machines. The fact that without electronics, no manufacturer has got a chance to stay among the world’s leaders and in lucrative world markets, forces all the important firms in the world to considerable investments in the development of electronic controls and drives of knitting machines.

The principles of the drive and control employed up to now have been based upon mechanical elements. For the drive of the small-diameter machines, the so-called brushless motors have been used, that are able to provide for a controlled drive including reverse motion. For the rocking movement of the needle cylinder, ingenious mechanical systems had to have been employed up to now.

Consequently, the present aim is to provide for the control of all the other functions of a small-diameter knitting machine by means of electronic, or eventually, pneumatic & electrical elements. For this purpose, pneumatic cylinders with electronic control of the input
of air are employed. However, the disadvantage of these systems consists of the fact that the movement of the pneumatic cylinder is not defined accurately, which can be critical, in particular when transferring masses within a short interval in time.

Therefore, electromechanical systems appear to be considerably more advantageous. One of the alternatives of the electromechanical systems consists in the connection of a mechanical section with a controlled stepping motor. The contribution presented here occupies itself with the project and its dynamical analysis.

Control of the density of the knitted fabric

The stitch density belongs among the most important characteristics when describing a knitted fabric. With density, there are related other important characteristics of the fabric, such as its elasticity, its extensibility and last but not least, its aesthetic properties.

The density can be characterised for example by the number of loops in a square piece of knitted fabric measuring 10 x 10 cm, or by the length of yarn in one loop, or by the number of courses and wales per 10 cm.

This characteristics of the knitted fabric is influenced by the length of the loop clearing, which is a parameter determined by the distance between the needle beards and the plane of the knocking-over sinkers. Consequently, for any change in the density of the knitted fabric it is essential to change the length of the yarn in the stitch, which can be effected by

a) Changing the tension of the yarn
b) Changing the magnitude of the take-up motion
c) Changing the magnitude of the stitch clearing

The principle employed most often to change the density of the knitted fabric is to change the magnitude of the stitch clearing is substantially made in two ways

1) changing the position of the plane of the knocking-over sinkers
2) changing the position of the clearing cams

For control of the density of the knitted fabric through the change of the position of the knocking-over plane, there serve vertical changes of the position of the needle cylinder, with a change of the distance between the needle beard and the plane of the knocking-over sinkers resulting. The principle of the control can be seen in Fig. No. 1.

![Fig. No. 1. Mechanism for changing the density of the yarn by changing the vertical position of the needle cylinder.](image1)

![Fig. No. 2. Shift of the clearing cams by means of the cam mechanism.](image2)
The needle cylinder 2, which rotates together with the plate ring 3, is seated upon the density cylinder 1 through the axial bearing 4. By means of this cylinder, it can move in the vertical direction, thus producing a change in the distance between the plane of the knocking-over sinkers and the needle beards, because the knocking-over sinkers, seated in the sinker ring, move together with the needle cylinder as well.

However, this system of control of the density of the knitted fabric has a number of disadvantages. It presents problems with the seating of the needle cylinder, it does not allow for control in individual systems of multi-feed knitting machines, and in particular, it does not allow for fast changes of the density at higher performances. Because of that, this principle is not prospective.

The other way to control the density of the knitted fabric consists in the vertical shift of the clearing cams with respect to the knocking-over plane. Fig. No. 2 shows the mechanism for the shift of cam 9 by means of cam 6 and stepping motor 1. Cam 6 with pulley 7 brings the cam downwards; spring 10 serves to bring it back. Screws 11, 12, 13 serve for the precise adjustment of the cam.

The cam mechanism that serves for the shift of the clearing cam, limits the maximum turning of the shaft of the stepping motor to an angle less than 360°. In this way, the maximum number of steps of the motor is limited, too, which can result in insufficient accuracy. The starting position is determined by the stop dog on the cam’s shaft, which limits machine performance as well, because at higher speeds, rebounds can occur on the stop dog.

An undeniable advantage of this mechanism consists in the shifting masses, which are considerably lower, the design is simple mechanically, and it is possible to control each system of the machine separately.

These advantages are employed in another way of shifting the clearing cams, the principle of which can be seen in Fig. No. 3.

![Fig. No. 3. Shift of the clearing cams by means of the motion screw and stepping motor](image)

In this concept, the cam mechanism is substituted by cam lever 5, nut 3 and screw 2, driven by stepping motor 1. The clearing cam is shifted upwards by cam lever 5 through adjusting screw 6, and it is brought back by means of the spring. The starting position is determined by stop edges 31 and 41 on the screw nut.
The number of steps of the motor is controlled by the commands from the control system of the knitting machine. Another advantage of this design is the high resolution of the position of the clearing cam. For example, at a motor step of 1.8° and a screw lead of 2 mm, one step of the motor corresponds to a lift of 0.01 mm of the nut, and that is further reduced by the gear on rocker arm 5.

Knitting technology concerning hosiery in particular, requires a stepless control of the fabric density with an accuracy of 0.02 mm, and however, in steps as well. At a step change, a relatively fast change of the cam position is required, namely through 0.4 mm in a period of 6 ms.

This requirement has been resolved on the knitting machine by another additional arm 6, governed by pneumatic cylinder 7 with adjusting screw 8, secured with another screw 9 and segment 10 (Fig. No. 4).

The purpose of the contribution presented here is to design a mechanism where both of the mentioned functions of the control of the fabric density may be carried out employing single drive.

1 ... stepping motor fastened to the machine frame (not shown here)
2 ... density screw
3 ... motion sensing nut
31 ... gearing on the sensing nut
4 ... adjustable ring
41 ... stop gearing
5 ... rocker lever of the density
6 ... additional lever for the density
7 ... pneumatic cylinder for the stepless change of the density
8 ... adjusting screw
9 ... setting screw
10 ... segment for securing the position of the adjusting screw
11 ... adjusting screw of the cam (not shown here)
12 ... link seating of the density lever in the sensing nut

Fig. No. 4. Stepless and step-type control of the density

**Mechanism for the step control of the density of the knitted fabric**

A convenient solution for the drive of such a mechanism seems to be a stepping motor, which can operate in an open loop and does not require feedback. However, there remains the question of mechanical overloading, when the motor loses its steps, and consequently may not be reliable; this question requires great attention. Because of this fact, it is necessary to carry out a thorough dynamical analysis of the mechanical section, choosing an adequate transmission ratio so that the dynamical loading moment and the frequency of the steps of the motor may satisfy the characteristics of the employed stepping motors.
The dynamical analysis is based upon the basic equation of motion of a system in the form of

\[ I_{\text{red}} \ddot{\varepsilon} = M_{\text{red}} \]

where \( I_{\text{red}} \) is the reduced moment of inertia of the reduction element upon which all the masses in the system have been reduced. \( \varepsilon \) is the acceleration of the reduction member, which is the motion screw. \( M_{\text{red}} \) is the force moment given by the reduction of all the force effects upon the system.

The reduced moment of inertia of the reduction element is determined by the equality of kinetic energies of the reduction element and the whole system according to the following relation

\[ \frac{1}{2} I_{\text{red}} \dot{\varepsilon}^2 = \frac{1}{2} m_z \dot{v}_z^2 + \frac{1}{2} I_p \dot{\omega}_p^2 + \frac{1}{2} m_M \dot{v}_M^2 + \frac{1}{2} I_\delta \dot{\omega}_\delta^2 \]

and consequently

\[ I_{\text{red}} = m_z \left( \frac{a_s}{2 \pi b} \right)^2 + I_p \left( \frac{s}{2 \pi b} \right)^2 + m_M \left( \frac{s}{2 \pi} \right)^2 + I_\delta \]

where \( I_{\text{red}} \) is the reduced mass moment of inertia of the reduction element

- \( \omega_\delta \) is the angular velocity of the reduction element
- \( m_z \) is the mass of the complete cam
- \( v_z \) is the cam velocity
- \( I_p \) is the mass moment of inertia of the density lever
- \( \omega_p \) is the angular velocity of the density lever
- \( m_M \) is the mass of the nut
- \( v_M \) is the velocity of the nut
- \( I_\delta \) is the mass moment of the inertia of the density screw

The mass parameters of the individual elements of the system have been determined theoretically, and their values are shown in table No. 1.
Tab. No. 1. Mass and force parameters of the system

<table>
<thead>
<tr>
<th>I_p [kg m²]</th>
<th>I_s [kg m²]</th>
<th>m_M [kg]</th>
<th>m_s [kg]</th>
<th>F_j [N]</th>
<th>F_p [N]</th>
<th>F_z [N]</th>
</tr>
</thead>
<tbody>
<tr>
<td>82.07•10⁻⁷</td>
<td>8.66•10⁻⁷</td>
<td>15•10⁻³</td>
<td>180•10⁻³</td>
<td>30</td>
<td>65</td>
<td>36.8</td>
</tr>
</tbody>
</table>

From the equality of the output on the reduction element and on all the elements of the system, it is possible to determine the reduced force moment acting upon the reduction element in the following form

\[ M_{red} = -F_z \cdot \frac{a \cdot s}{2 \cdot \pi \cdot b} - m_p \cdot g \cdot \frac{s \cdot c}{2 \cdot \pi \cdot b} - m_M \cdot g \cdot \frac{s}{2 \cdot \pi} + M_H \]  \hspace{0.5cm} (4)

\( F_z \) is the resulting force acting upon the clearing cam, and it is determined by the relation

\[ F_z = -F_j + F_p + m_s g \]  \hspace{0.5cm} (5)

where \( F_j \) is the resulting force from the needles acting upon the cam \( F_j = 30 \, N \)

\( F_p \) is the force from the springs (2x2 springs ordered in series) \( F_p = 65 \, N \)

Using the relations (3) and (4) in the equation of motion (1), we can express the driving moment in the following form:

\[ M_H = \left[ m_s \left( \frac{a \cdot s}{2 \cdot \pi \cdot b} \right)^2 + I_p \left( \frac{s}{2 \cdot \pi} \right)^2 + m_M \left( \frac{s}{2 \cdot \pi} \right)^2 + I_s \right] \cdot \frac{a_z}{s} + \]

\[ + F \cdot \frac{a \cdot s}{2 \cdot \pi \cdot b} + m_p \cdot g \cdot \frac{s \cdot c}{2 \cdot \pi \cdot b} + m_M \cdot g \cdot \frac{s}{2 \cdot \pi} \]  \hspace{0.5cm} (6)

For the prescribed values of the stroke \( h=0.4 \, \text{mm} \) within the period \( t=0.006 \, \text{s} \), it is essential to provide for the necessary value of acceleration, which places relatively high requirements upon the driving unit, i.e. the stepping motor, at the same time. According to the information obtained from the manufacturer, the employed stepping motor allows for the following start-ups to the frequency

- From zero to 1000 steps/s within 1.6 ms
- From zero to 2000 steps/s within 3.3 ms

under the condition that the loading moment upon the motor will not exceed the values given by the moment characteristics of the motor. If we consider the section of the starting run of the cam on path \( h \) solely, at a constant acceleration, the value of the acceleration is given by the relation

\[ a_z = \frac{2h}{t^2} \]  \hspace{0.5cm} (7)

For the required values \( h=0.4 \, \text{mm} \) and \( t=0.006 \, \text{s} \), the value of the acceleration amounts to \( a_z=22.2 \, \text{ms}^{-2} \).

Considering the maximum values of the acceleration of the stepping motor indicated by its manufacturer, by means of the present execution it is possible to achieve an acceleration of the cam amounting to \( a_z=1.17 \, \text{ms}^{-2} \) (screw lead \( s=1.25 \, \text{mm} \)).
Table No. 2 shows the values of acceleration $a_z$ and the necessary driving moment $M_H$ in dependence upon the lead of the motion screw.

<table>
<thead>
<tr>
<th>Screw lead $s$ [m]</th>
<th>Acceleration of screw $[\text{rad.s}^{-2}]$</th>
<th>Acceleration of cam $a_z$ [m.s$^{-2}$]</th>
<th>Necessary moment $M_H$ [Nm]</th>
<th>Screw lead $s$ [m]</th>
<th>Acceleration of screw $[\text{rad.s}^{-2}]$</th>
<th>Acceleration of cam $a_z$ [m.s$^{-2}$]</th>
<th>Necessary moment $M_H$ [Nm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1.25 \times 10^{-3}$</td>
<td>19337.45</td>
<td>1.17</td>
<td>0.019</td>
<td>$7.00 \times 10^{-3}$</td>
<td>19337.45</td>
<td>6.58</td>
<td>0.030</td>
</tr>
<tr>
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<td>19337.45</td>
<td>1.41</td>
<td>0.020</td>
<td>$8.00 \times 10^{-3}$</td>
<td>19337.45</td>
<td>7.52</td>
<td>0.032</td>
</tr>
<tr>
<td>$1.75 \times 10^{-3}$</td>
<td>19337.45</td>
<td>1.64</td>
<td>0.020</td>
<td>$9.00 \times 10^{-3}$</td>
<td>19337.45</td>
<td>8.46</td>
<td>0.034</td>
</tr>
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<td>$2.00 \times 10^{-3}$</td>
<td>19337.45</td>
<td>1.88</td>
<td>0.020</td>
<td>$1.00 \times 10^{-2}$</td>
<td>19337.45</td>
<td>9.40</td>
<td>0.037</td>
</tr>
<tr>
<td>$2.50 \times 10^{-3}$</td>
<td>19337.45</td>
<td>2.35</td>
<td>0.021</td>
<td>$1.20 \times 10^{-2}$</td>
<td>19337.45</td>
<td>11.28</td>
<td>0.041</td>
</tr>
<tr>
<td>$3.00 \times 10^{-3}$</td>
<td>19337.45</td>
<td>2.82</td>
<td>0.022</td>
<td>$1.40 \times 10^{-2}$</td>
<td>19337.45</td>
<td>13.16</td>
<td>0.045</td>
</tr>
<tr>
<td>$3.50 \times 10^{-3}$</td>
<td>19337.45</td>
<td>3.29</td>
<td>0.023</td>
<td>$1.60 \times 10^{-2}$</td>
<td>19337.45</td>
<td>15.04</td>
<td>0.050</td>
</tr>
<tr>
<td>$4.00 \times 10^{-3}$</td>
<td>19337.45</td>
<td>3.76</td>
<td>0.024</td>
<td>$1.80 \times 10^{-2}$</td>
<td>19337.45</td>
<td>16.92</td>
<td>0.055</td>
</tr>
<tr>
<td>$4.50 \times 10^{-3}$</td>
<td>19337.45</td>
<td>4.23</td>
<td>0.025</td>
<td>$2.00 \times 10^{-2}$</td>
<td>19337.45</td>
<td>18.80</td>
<td>0.059</td>
</tr>
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<td>$5.00 \times 10^{-3}$</td>
<td>19337.45</td>
<td>4.70</td>
<td>0.026</td>
<td>$2.20 \times 10^{-2}$</td>
<td>19337.45</td>
<td>20.67</td>
<td>0.064</td>
</tr>
<tr>
<td>$6.00 \times 10^{-3}$</td>
<td>19337.45</td>
<td>5.64</td>
<td>0.028</td>
<td>$2.36 \times 10^{-2}$</td>
<td>19337.45</td>
<td>22.22</td>
<td>0.068</td>
</tr>
</tbody>
</table>

The values show that a relatively considerable transmission ratio must be realised between the motion screw and the cam, in order to obtain the necessary acceleration of 22.2 ms$^{-2}$. The same is determined here by the lead on screw $s=23.6$ mm. At the same time, the table shows that the values of the loading moment $M_H$ are not very high. However, it is necessary to bear in mind that these values do not consider the run-out phase of the stroke, which further worsens the situation.

**Optimum alternative of the mechanism for the step change of the density of the knitted fabric**

The above-mentioned results show that the mechanism for the step change of the density of the knitted fabric can be designed under the following conditions:

1) Increasing the gear ratio between the motion screw and the cam. This requirement can be met adapting the structure of the mechanism in compliance with Fig. No. 6.

$v_z$ … cam velocity

$\omega_p$ … angular velocity of the lever

$v_m$ … velocity of the sensing head

$\omega_\delta$ … angular velocity of the density screw

Basic dimensions:

- $a = 14.5$ mm
- $b = 47.5$ mm
- $c = 23.695$ mm

Screw lead $s = 1.25$ mm

*Fig. No. 6. Adapted mechanism for the control of density of the knitted fabric*
Employed stepping motor of the firm MAE:

MAE HY 200 1713

Step angle K=1.8°

Fig. No. 7. Moment characteristics

2) The clearing cam can be divided into the unmovable – static part and the movable part. For the proper function of the cam, it is necessary to move its part only; due to this arrangement, the mass to be transferred is reduced by approximately one half.

Moreover, as a consequence of this arrangement the number of needles to be cleared by the cam is reduced. Therefore, the force from the needles is reduced to the value

\[ F_j = 10 \text{ N} \]  \hspace{1cm} (8)

and the corresponding force of the springs will amount to

\[ F_p = 21.7 \text{ N} \]  \hspace{1cm} (9)

As a result, the total force acting upon the cam will be

\[ F_z = -F_j + F_p + m_z g = 13.5 \text{ N} \]  \hspace{1cm} (10)

3) With respect to the technological properties of the knitted fabric, changes lower than 0.05 mm can be considered non-essential, bearing no effect upon the appearance of the fabric. Because of that, the section of the stroke up to 0.05 mm can be pre-set before the proper stroke of the cam, and the same can be carried out in the run-out phase, too.

Due to this arrangement, the time required for the step change of the density is extended considerably, because a parabolic course of the path is involved. The step change can be programmed easily with pre-set sections, thus gaining more necessary time for the stroke of the clearing cam.

For the dynamic analysis of the structure of the mechanism under the above-mentioned conditions, we employ the equation of motion (1).

<table>
<thead>
<tr>
<th>( I_o ) [kg m²]</th>
<th>( I_s ) [kg m²]</th>
<th>( m_M ) [kg]</th>
<th>( m_z ) [kg]</th>
<th>( F_j ) [N]</th>
<th>( F_p ) [N]</th>
<th>( F_z ) [N]</th>
</tr>
</thead>
<tbody>
<tr>
<td>23.41\times10^{-7}</td>
<td>8.66\times10^{-7}</td>
<td>15\times10^{-3}</td>
<td>90\times10^{-3}</td>
<td>10</td>
<td>21.7</td>
<td>13.5</td>
</tr>
</tbody>
</table>
In a manner analogous to the existing design, employing the equation of motion (1) of the reduction element of the system, we find the driving moment that must be produced by the stepping motor, in the following form

\[
M_H = \left[ m_s \left( \frac{a_s s}{2 \pi b} \right)^2 + l_p \left( \frac{s}{2 \pi b} \right)^2 + m_M \left( \frac{s}{2 \pi} \right)^2 + l_s \right] s
\]

\[+ F \frac{a_s}{2 \pi b} + m_p \frac{c}{2 \pi b} - m_M \frac{s}{2 \pi}\]

(11)

Table No. 4. Parameters of the adapted mechanism and stepping motor

<table>
<thead>
<tr>
<th>Clearing cam</th>
<th>Double-arm density lever</th>
</tr>
</thead>
<tbody>
<tr>
<td>Force from needles $F_j$ [N]</td>
<td>Acceleration of screw [rad.s$^{-2}$]</td>
</tr>
<tr>
<td>10</td>
<td>19320.8</td>
</tr>
</tbody>
</table>

Table information on the motor

| Moment of inertia of the rotor [kg.m$^2$] | Step angle [°] | Step accuracy [%] |
| 18•10$^{-7}$ | 1.8 | 5 |

The optimum alternative of the design is based upon the parameters shown in Table No. 4 and the structure according to Fig. No. 6. The resulting values of kinematic quantities are shown in Table No. 5.
Table No. 5. Values of kinematic quantities for the optimum alternative of the mechanism for density control

<table>
<thead>
<tr>
<th>Time t [s]</th>
<th>Position x, z [m]</th>
<th>Frequency f [step/s]</th>
<th>Velocity of cam $v_z$ [ms$^{-1}$]</th>
<th>Velocity of screw $\omega_s$ [rad.s$^{-1}$]</th>
<th>Turning of screw $\Phi$ [rad]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5.00•10^{-4}</td>
<td>1.28•10^{-6}</td>
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<td>5.13•10^{-3}</td>
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<td>1.54•10^{-2}</td>
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Conclusion

In this optimum alternative, a considerably lower constant acceleration $a_z=10.25 \text{ ms}^{-2}$ is sufficient. As a matter of fact, the pre-set sections of the cam stroke extend the time necessary for the step change twice, without any harm to the quality of the knitted fabric. The maximum frequency of the motor steps amounts to the value of 3843 steps/s. The necessary driving moment of the motor is determined by the relation
\[ M_m = M_H + I_r \dot{\epsilon}_s \]  

(12)

where \( I_r \) is the mass moment of inertia of the rotor of the motor  
\( M_H \) is the driving moment for the mechanical section of the system.

and it amounts to \( M_m = 0.059 \, Nm \).

The maximum velocity of the cam does not exceed \( 6.41 \times 10^{-2} \, \text{m.s}^{-2} \), the angular velocity of the motion screw \( \omega_{\text{max}} = 120 \, \text{rad.s}^{-1} \), and the maximum turning of the rotor of the stepping motor with the motion screw is 0.756 rad.

The results obtained here present a specific requirement upon the control of the stepping motor: it should operate in such a way that the step change may start to be effected with an advance determined by the value of the stroke of 0.05 mm for example (see the Table 5). Once it has started, it is necessary to provide for a linear increase of the step frequency up to the value of \( f_{\text{max}} = 3843 \, \text{steps/s} \). In the run-out section, the step frequency is lowered again linearly till coming to zero.

In the next phase of the solution of the problem in question, it will be necessary to verify the behaviour and the reliability of the driving stepping motor, including experimental analysis. The results of the solution will be able to serve for the development and modernisation of small-diameter knitting machines, in particular in the enterprise UNIPLET Trebic, which is the sole domestic manufacturer of small-diameter knitting machines.

References: