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Method of Separating Fabric from a Stack – Part 2

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Abstract
A mathematical model of the gripper mechanism with an electric drive, characterised by an increased work surface is presented in the paper. Equations describing the kinematic and dynamic characteristics have been formulated for this model. The resulting equations have been solved numerically. The calculation results illustrating the rheological reaction of the material to the operation of the gripper have been shown in diagrams.

Key words: *gripper for textiles, computer control, mathematical model, garment production, robotisation.*

Introduction. Mathematical models of grippers for textiles

Existing grippers very often use springs for compression [1 – 3]. Textiles are exposed to destruction because come into contact with the jaws in a very small area and they do not have the ability to control the compression force. Papers [4, 5] proposed an improvement associated with it, where the spring is replaced with a motor which is intended to prevent the crossing of the permissible pressures for the fabric so that there is no destruction.

Despite the use of the motor instead of the spring and the ability to control the size of the pressure on the material, forces acting pointwise on textiles may still be too large.

Reducing pressures necessary to maintain the fabric is possible by increasing the contact surface of the jaws. Therefore the solution to this problem proposed is agripper for textiles with parallel fingers [5]. The fingers are in contact with the separating fabric over a much larger area than grippers gripping the fabric in a "pinch" [4].

The grippers discussed could serve as such for textiles, but they need to have the fabric between their fingers. Effective separation of the fabric requires a mechanism introducing the fabric between its fingers. This paper describes a mechanism for introducing the fabric between fingers using frictional forces, which can be realized by using an endless belt, pulling the fabric by force of friction in the direction of the blockage place, where is a fold formed entering between the belt and foot. The further movement of the belt will unfold the fabric between the elements involved in separating the fabric layer [6].

Equations of motion

Employing the principle of virtual works for moving parts of the gripper described in [6] in ***Figure 1*** (see page 80), supplemented with moments of inertia of the guide rollers of the belt I_{2c}, I_{3c}, I_{4c}, which move with velocity $\varphi_2 r_{2c}$, the frictional forces between the belt and separating fabric layer T_1 and T_2 and the weight of the separating fabric m_h and m_v, we can write a dynamic equation of motion in the following form:

$$\begin{aligned} &M_m d\varphi_1 - I_{1c}\frac{d^2\varphi_1}{dt^2}d\varphi_1 - I_{2c}\frac{d^2\varphi_2}{dt^2}d\varphi_2 + \\ &- I_{3c}\frac{d^2\varphi_3}{dt^2}d\varphi_3 - I_{4c}\frac{d^2\varphi_4}{dt^2}d\varphi_4 + \\ &- m_{tk}\frac{d^2\varphi_2}{dt^2}d\varphi_2 r_{2c}^2 - (T_1 + T_2)d\varphi_2 r_{2c} = 0 \end{aligned} \quad (1)$$

The forces of friction between the belt and separation fabric layer equal, respectively, to:

$$T_1 = \mu_p(N_v + m_h g),\ T_2 = \mu_p N_h \quad (2)$$

Equation 1, taking account of the friction forces T_1 and T_2 (2) and masses m_h and m_v (4a, 4b), as described in [6], after the transformation can be written as:

$$\begin{aligned} &I_{1c}\frac{d^2\varphi_1}{dt^2} + I_{2c}\frac{d^2\varphi_2}{dt^2}\frac{r_{1c}}{R_c} + I_{3c}\frac{d^2\varphi_3}{dt^2}\frac{r_{1c}r_{2c}}{R_c r_{3c}} + \\ &+ I_{4c}\frac{d^2\varphi_4}{dt^2}\frac{r_{1c}r_{2c}}{R_c r_{4c}} + (m_v + m_h)\frac{d^2\varphi_2}{dt^2}\frac{r_{1c}r_{2c}^2}{R_c} + \\ &+ \mu_p(N_v + N_h + m_h g)\frac{r_{1c}r_{2c}}{R_c} - M_m = 0 \end{aligned} \quad (3)$$

Using the formulas defining the derivative of a composite function:

$$\begin{aligned} \frac{d^2\varphi_2}{dt^2} &= \frac{d^2\varphi_1}{dt^2}\frac{d\varphi_2}{d\varphi_1} + \left(\frac{d\varphi_1}{dt}\right)^2\frac{d^2\varphi_2}{d\varphi_1^2} \\ \frac{d^2\varphi_3}{dt^2} &= \frac{d^2\varphi_1}{dt^2}\frac{d\varphi_3}{d\varphi_1} + \left(\frac{d\varphi_1}{dt}\right)^2\frac{d^2\varphi_3}{d\varphi_1^2} \\ \frac{d^2\varphi_4}{dt^2} &= \frac{d^2\varphi_1}{dt^2}\frac{d\varphi_4}{d\varphi_1} + \left(\frac{d\varphi_1}{dt}\right)^2\frac{d^2\varphi_4}{d\varphi_1^2} \end{aligned} \quad (4)$$

and substituting to expression (3) we obtain a second order differential equation:

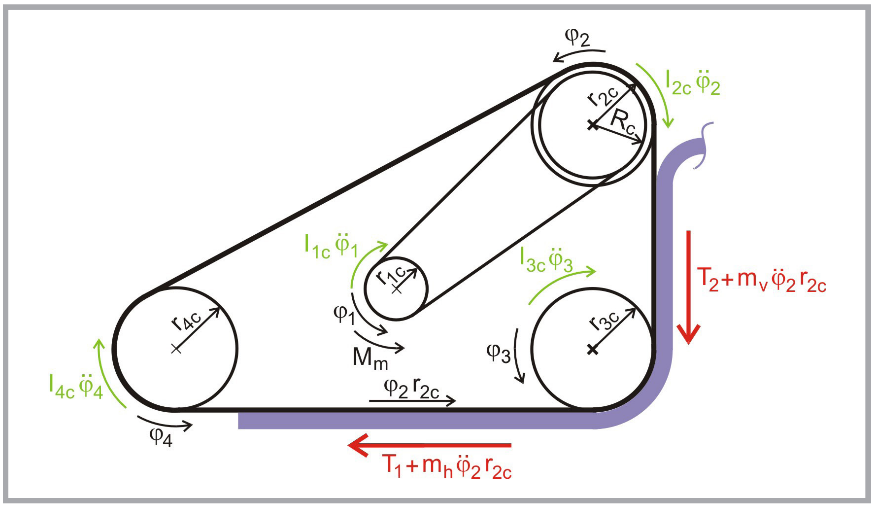

Figure 1. *Distribution and directions of moments in the gripper's movable part system described in [6] in Figure 1; I_{1c}, I_{2c}, I_{3c}, I_{4c}, - moments of inertia of guide rollers of the belt, $\varphi_{1,\dots,4}$ - angles of rotation of guide rollers of the belt, r_{1c}, r_{2c}, r_{3c}, r_{4c}, R_c - radii of rolls of the gripper, M_m – drive torque of the motor of rolls, T_1 i T_2 - boundary frictional forces between the belt and separating layers of the fabric, m_h – mass of the fabric lying on the table (not picked up yet), m_v – mass of the fabric between the foot and belt.*

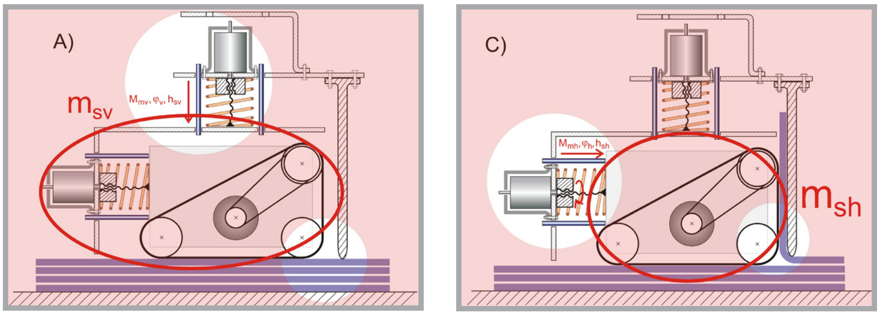

Figure 2. *Step of pressing the textile package to the table (A) and a compression of separated layer between the foot and moving part of the gripper (C) described in [6], m_{sv}, m_{sh} - weight of the respective elements of the gripper.*

$$\left[I_{1c}+I_{2c}\frac{d\varphi_2}{d\varphi_1}\frac{r_{1c}}{R_c}+I_{3c}\frac{d\varphi_3}{d\varphi_1}\frac{r_{1c}r_{2c}}{R_c r_{3c}}+I_{4c}\frac{d\varphi_4}{d\varphi_1}\frac{r_{1c}r_{2c}}{R_c r_{4c}}+\right.$$
$$\left.+(m_v+m_h)\frac{d\varphi_2}{d\varphi_1}\frac{r_{1c}r_{2c}^2}{R_c}\right]\frac{d^2\varphi_1}{dt^2}+$$
$$+\left[I_{2c}\frac{d^2\varphi_2}{d\varphi_1^2}\frac{r_{1c}}{R_c}+I_{3c}\frac{d^2\varphi_3}{d\varphi_1^2}\frac{r_{1c}r_{2c}}{R_c r_{3c}}+I_{4c}\frac{d^2\varphi_4}{d\varphi_1^2}\frac{r_{1c}r_{2c}}{R_c r_{4c}}+\right. \tag{5}$$
$$\left.+(m_v+m_h)\frac{d^2\varphi_2}{d\varphi_1^2}\frac{r_{1c}r_{2c}^2}{R_c}\right]\left(\frac{d\varphi_1}{dt}\right)^2+$$
$$+\mu_p(N_v+N_h+m_h g)\frac{r_{1c}r_{2c}}{R_c}-M_m=0$$

Between the angles of rotation $\varphi_{1,\dots,4}$ and the radii of circles r_{1c}, r_{2c}, r_{3c}, r_{4c}, R_c can be formulated thus:

$$\varphi_2 R_c=\varphi_1 r_{1c},\ \frac{\varphi_2}{\varphi_1}=\frac{r_{1c}}{R_c},\ \frac{d\varphi_2}{d\varphi_1}=\frac{r_{1c}}{R_c} \tag{6}$$
$$\varphi_2 r_{2c}=\varphi_3 r_{3c}=\varphi_4 r_{4c}\quad \varphi_2=\varphi_1\frac{r_{1c}}{R_c}$$

$$\frac{d\varphi_A}{dt}=\varphi_B$$
$$\frac{d\varphi_B}{dt}=\frac{M_m-\mu_p(N_v+N_h+m_h g)\frac{r_{1c}r_{2c}}{R_c}-\left[I_{2c}\frac{d^2\varphi_2}{d\varphi_A^2}\frac{r_{1c}}{R_c}+I_{3c}\frac{d^2\varphi_3}{d\varphi_A^2}\frac{r_{1c}r_{2c}}{R_c r_{3c}}+I_{4c}\frac{d^2\varphi_4}{d\varphi_A^2}\frac{r_{1c}r_{2c}}{R_c r_{4c}}+(m_v+m_h)\frac{d^2\varphi_2}{d\varphi_A^2}\frac{r_{1c}r_{2c}^2}{R_c}\right]\left(\frac{d\varphi_A}{dt}\right)^2}{I_{1c}+I_{2c}\left(\frac{r_{1c}}{R_c}\right)^2+I_{3c}\left(\frac{r_{1c}r_{2c}}{R_c r_{3c}}\right)^2+I_{4c}\left(\frac{r_{1c}r_{2c}}{R_c r_{4c}}\right)^2+(m_v+m_h)\left(\frac{r_{1c}r_{2c}}{R_c}\right)^2} \tag{8}$$

Equation 8.

$$\varphi_2 r_{2c}=\varphi_3 r_{3c},\ \varphi_1\frac{r_{1c}r_{2c}}{R_c}=\varphi_3 r_{3c}$$
$$\frac{\varphi_3}{\varphi_1}=\frac{r_{1c}r_{2c}}{R_c r_{4c}},\ \frac{d\varphi_3}{d\varphi_1}=\frac{r_{1c}r_{2c}}{R_c r_{3c}},$$
$$\varphi_2 r_{2c}=\varphi_4 r_{4c},\ \varphi_1\frac{r_{1c}r_{2c}}{R_c}=\varphi_4 r_{4c} \tag{7}$$
$$\frac{\varphi_4}{\varphi_1}=\frac{r_{1c}r_{2c}}{R_c r_{4c}},\ \frac{d\varphi_4}{d\varphi_1}=\frac{r_{1c}r_{2c}}{R_c r_{4c}}$$

After substituting ***Equations 6 and 7*** into ***Equation 5***, we then obtain a system of ***Equation 8*** of the first order.

For the purpose of numerical calculation of a simplified system of ***Equations 8***, assuming that the guide roller belts are identical, and their moments of inertia I_{2c}, I_{3c}, I_{4c}, radii r_{2c}, r_{3c}, r_{4c} and angles of rotation φ_2, φ_3, φ_4 are created equal.

Using relationships (6) and (7) between the angles of rotation and radii of wheels, we can write that:

$$\frac{d\varphi_2}{d\varphi_1}=\frac{d\varphi_3}{d\varphi_1}=\frac{d\varphi_4}{d\varphi_1}=\frac{r_{1c}}{R_c}\ \text{and}$$
$$\frac{d^2\varphi_2}{d\varphi_1^2}=\frac{d^2\varphi_3}{d\varphi_1^2}=\frac{d^2\varphi_4}{d\varphi_1^2}=0 \tag{9}$$

After substituting ***Equation 9*** into the system of ***Equations 8***, the following is obtained:

$$\frac{d\varphi_A}{dt}=\varphi_B$$
$$\frac{d\varphi_B}{dt}=\frac{M_m-\mu_p(N_v+N_h+m_h g)\frac{r_{1c}r_{2c}}{R_c}}{I_{1c}+3I_{2c}\left(\frac{r_{1c}}{R_c}\right)^2+(m_v+m_h)\left(\frac{r_{1c}r_{2c}}{R_c}\right)^2} \tag{10}$$

While manipulating a package of fabrics, the gripper presses the fabric lying on the table in a stack (***Figure 2.A***) and a layer is separated from the stack between the foot and gripper's movable part (***Figure 2.C***).

The motion of the gripper along the vertical direction is initiated by an electric motor *9* with a driving torque M_{mv} and an angle of rotation of the main shaft φ_v by means of a screw *7* with a pitch h_{sv}, which transforms the rotary motion of the motor into a vertical translatory one [6].

Analogously the motion of the gripper along the horizontal direction is performed by means of an electric motor *18* with a moment M_{mh} and angle of rotation of the main shaft φ_h and a screw *16* of pitch h_{sh} [6].

Figures 3 and ***4*** present the distribution of accelerations and forces acting on the mass of the gripper m_{sh} along the horizontal and m_{sv} vertical direction.

The mass m_{sh} consists of gripper elements, i.e. a plate *13* with three belt guide rollers *3*, an electric motor *4* and a rubber belt *2* (***Figure 2.C*** and ***1*** [6]), while the mass m_{sv} consists of a mass m_{sh}, a spring *15* and guides *19* for stabilisation of the gripper motion along the horizontal direction, an electric motor *18*, and casing *14* (***Figure 2.A*** and ***1*** [6]).

The dynamic equations of motion for the systems shown in ***Figure 3*** can be presented using the principle of virtual works:

$$\begin{aligned} M_{mh} - N_h \frac{dx_h}{d\varphi_h} - m_{sh} \frac{d^2x_h}{dt^2} \frac{dx_h}{d\varphi_h} = 0 \\ M_{mv} - N_v \frac{dx_v}{d\varphi_v} - m_{sv} \frac{d^2x_v}{dt^2} \frac{dx_v}{d\varphi_v} = 0 \end{aligned} \tag{11}$$

The linear coordinates x_h and x_v and angular coordinates φ_h and φ_v define the position of the systems with masses m_{sh} and m_{sv}. Motion functions $x_h = x_h(\varphi_h)$ and $x_v = x_v(\varphi_v)$, which define geometrical relationships between the rotary motion of motors *9* and *18* and the horizontal and vertical motion of the gripper, are determined as:

$$x_h = \frac{\varphi_h}{2\pi} h_{sh}, \quad x_v = \frac{\varphi_v}{2\pi} h_{sv} \tag{12}$$

where h_{sh} and h_{sv} mean the movement of the movable part of the gripper attributable to one rotation of the motor shaft.

From the above equations, the following can be obtained:

$$\begin{aligned} \frac{dx_h}{d\varphi_h} = \frac{h_{sh}}{2\pi}, \quad \frac{d^2x_h}{d\varphi_h^2} = 0 \\ \frac{dx_v}{d\varphi_v} = \frac{h_{sv}}{2\pi}, \quad \frac{d^2x_v}{d\varphi_v^2} = 0 \end{aligned} \tag{13}$$

Employing the formula that defines a derivative of the complex function:

$$\frac{d^2x_v}{dt^2} = \frac{d^2\varphi_v}{dt^2} \frac{dx_v}{d\varphi_v} + \left(\frac{d\varphi_v}{dt}\right)^2 \frac{d^2x_v}{d\varphi_v^2} \tag{14}$$

which after taking into account relations (13) and after substituting to equations (11), we obtain the second order differential equations:

$$\begin{aligned} m_{sh}\left(\frac{h_{sh}}{2\pi}\right)^2 \frac{d^2\varphi_h}{dt^2} = M_{mh} - N_h \frac{h_{sh}}{2\pi} \\ m_{sv}\left(\frac{h_{sv}}{2\pi}\right)^2 \frac{d^2\varphi_v}{dt^2} = M_{mv} - N_v \frac{h_{sv}}{2\pi} \end{aligned} \tag{15}$$

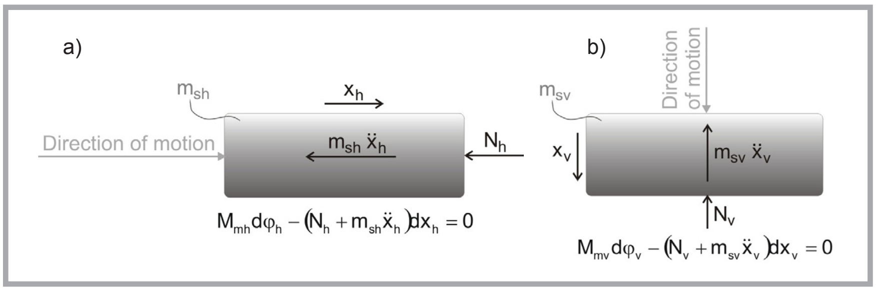

Figure 3. *Distribution of acceleration and forces acting on the mass of the gripper moving along the horizontal (a) and vertical (b) direction, driven by an electric motor 19 (a) and 9 (b)[6].*

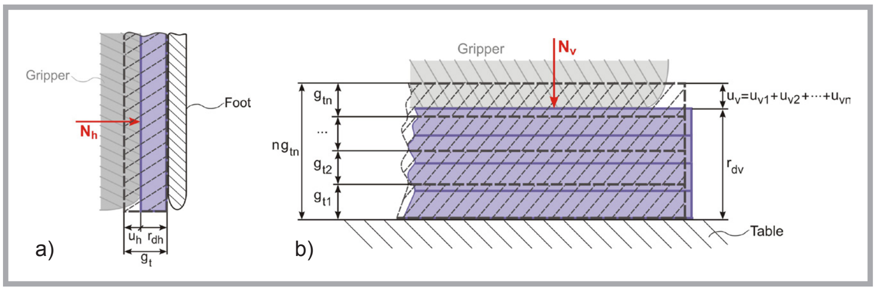

Figure 4. *Scheme of compression of the fabric layer with a force N_h (a) and N_v (b).*

Equations 15 are then written in the form of first-order equations for computer solution of the method of numerical integration:

$$\begin{aligned} \frac{d\varphi_{hB}}{dt} = \varphi_{hB} \quad \frac{d\varphi_{hB}}{dt} = \frac{M_{mh} - N_h \frac{h_{sh}}{2\pi}}{m_{sh}\left(\frac{h_{sh}}{2\pi}\right)^2} \\ \frac{d\varphi_{hA}}{dt} = \varphi_{hA} \quad \frac{d\varphi_{hA}}{dt} = \frac{M_{mv} - N_v \frac{h_{sv}}{2\pi}}{m_{sv}\left(\frac{h_{sv}}{2\pi}\right)^2} \end{aligned} \tag{16}$$

In paper [7] a model of fabric in the form of serially connected elements - springs and silencers has been described. For the purposes of this study nonlinear deformation (third degree) of the compression material has been selected. Assumed values of the elasticity constants of the fabric k_{h1}, k_{h2}, k_{v1} and k_{v2} describing e the deformation of the third degree for the sample selected, were determined on the basis of the results given in [8]. The relationships between compressive forces N_h and deformations u_h in the fabric layer between the foot and gripper's movable part (***Figure 4.a***) have been assumed in the following form:

$$\begin{aligned} N_h = \frac{k_{h1}}{g_t n_{ilh} + g_t \frac{L_t}{L_{tv}}} u_h + \\ + \frac{k_{h2}}{g_t n_{ilh} + g_t \frac{L_t}{L_{tv}}} u_h^3 + c_h \frac{du_h}{dt} \\ \text{for } u_h > 0 \\ N_h = 0 \text{ for } u_h \le 0 \end{aligned} \tag{17}$$

while the package of fabrics lying on the table (***Figure 4.b***) has been assumed in the following form:

$$\begin{aligned} N_v = \frac{k_{v1}}{g_t n_{ilv} + g_t \frac{L_t}{L_{th}}} u_v + \\ + \frac{k_{v2}}{g_t n_{ilv} + g_t \frac{L_t}{L_{th}}} u_v^3 + c_{tv} \frac{du_v}{dt} \\ \text{for } u_v > 0 \text{ and } L_h > 0.001 \end{aligned} \tag{18}$$

$$\begin{aligned} N_v = \frac{k_{v1}}{g_t n_{ilv}} u_v + \frac{k_{v2}}{g_t n_{ilv}} u_v^3 + c_{tv} \frac{du_v}{dt} \\ \text{for } u_v > 0 \text{ and } L_h \le 0.001 \\ N_v = 0 \text{ for } u_v \le 0 \end{aligned}$$

where N_h denotes the force that compresses the fabric between the foot and the gripper's movable part, N_v the force that compresses the package of fabrics lying on the table, (k_{h1}, k_{h2}, k_{v1}, k_{v2}) elasticity constants, c_{th}, c_{tv} damping coefficients, u_h, u_v compression, g_t thickness of one layer of fabric, $n_{ilh} = 0$, 1 or 2 [6] the number of layers of the compressing fabric between the foot and gripper belt, n_{ilv} the number of layers in the stack, L_t the total length of the fabric lying on the table, L_{th} the length of fabric lying on the table calculated by the formula (5a [6]), L_{tv} length of the compression fabric located between the foot and belt (5b [6]).

$$\begin{aligned} u_h = n_{ilh} g_t - r_{dh}, \\ u_v = u_{v1} + u_{v2} + \ldots + u_{vn} \\ u_v = n_{ilv} g_t - r_{dv} \end{aligned} \tag{19}$$

$$r_{dh} = x_{0h} - \frac{\varphi_h}{2\pi} h_{sh}, \; r_{dv} = x_{0v} - \frac{\varphi_v}{2\pi} h_{sv} \quad (20)$$

$$\frac{du_h}{dt} = -\frac{dr_{dh}}{dt} = \frac{h_{sh}}{2\pi}\frac{d\varphi_h}{dt}, \qquad \frac{du_v}{dt} = -\frac{dr_{dv}}{dt} = \frac{h_{sv}}{2\pi}\frac{d\varphi_v}{dt} \quad (21)$$

In the sample the normal forces N_h and N_v compress for $r_{dh} < g_t$, $r_{dv} < g_t$, where g_t stands for the thickness of one layer of the fabric. If $r_{dh} \geq g_t$ and $r_{dv} \geq g_t$ then the forces $N_h = 0$ and $N_v = 0$. In ***Figure 6*** $u_{v1} = u_{v2} = ... = u_{vn}$ denotes compressions of subsequent fabric layers, whose thicknesses are equal to $g_{t1} = g_{t2} = ... = g_{tn}$; r_{dh} is the distance between the foot and the gripper's movable part, calculated with relationship (20); r_{dv} is the distance of the gripper from the table, calculated with relationship (20), where x_{0h} and x_{0v} mean distances r_{dh} and r_{dv} at the initial time instants.

The logic feedbacks controlling the gripper's operation and stating that if the compressive forces are lower than the assigned forces $N_h < N_{set}$ and $N_v < N_{set}$, then the values of the supply voltage increases by Δe_h ($e_h := e_h + \Delta e_h$) and Δe_v ($e_v := e_v + \Delta e_v$), have been introduced into the computer program. On the other hand, if $N_h > N_{set}$ and $N_v > N_{set}$, then $e_h := e_h - \Delta e_h$ and $e_v := e_v - \Delta e_v$. N_{set} denotes the force with which the gripper should act on the fabric. Simultaneously the current intensity cannot exceed the admissible value.

The increment values of the electromotive forces Δe_h and Δe_v in the following steps are expressed as products of current electromotive forces e_h and e_v, increases in forces ΔN_h and ΔN_v relative to the setpoint force ($\Delta N_h = N_h - N_{set}$ and $\Delta N_v = N_v - N_{set}$), integration step Δt and numbers ε_h and ε_v agreed in order to reach a converging solution:

$$\Delta e_v = e_v \cdot \Delta N_v \cdot \Delta t \cdot \varepsilon_v \qquad \Delta e_h = e_h \cdot \Delta N_h \cdot \Delta t \cdot \varepsilon_h \quad (22)$$

The equations of moments of the motors: driving the rollers which lead belt *4*, initiate the vertical motion of gripper *9*, and initiate the horizontal motion of the gripper *18,* as shown in ***Figure 1*** in [6], are expressed by the formulas:

$$\frac{dM_m}{dt} = \frac{1}{T_m}\left[c_m\left(\Omega_m - \frac{d\varphi_1}{dt}\right) - M_m\right] \quad (23)$$

$$T_m = \frac{L_m}{R_m}, \; c_m = \frac{K_{tm} \cdot K_{bm}}{R_m}, \qquad \Omega_m = \frac{e_m}{K_{bm}}, \; i_m = \frac{M_m}{K_{tm}} \quad (24)$$

where T_m denotes the motor time constant, c_m - motor rigidity, Ω_m - motor angular velocity at which the moment is equal to zero, i_m - current intensity, L_m - inductance, R_m - resistance, e_m - supply voltage, K_{bm}, K_{tm} - motor constants, and φ_1 - angle of rotation of the motor.

Assumptions for the calculation and results

The computer program simulates the work of the gripper, extended by equation (4 - 8), as described in [6] and (1 - 24). Appropriate parameters for the gripper, motors and textiles have been selected as follows:

- dimensions: $r_{1c} = 0.0062$ m, $r_{2c} = 0.0138$ m, $R_c = 0.0116$ m, $x_{0v} = 0.008$ m, $x_{0h} = 0.008$ m,
- mass moment of inertia of the guide roller belt: $I_{2c} = 55 \cdot 10^{-7}$ kgm²,
- masses of relevant parts of the gripper: $m_{sh} = 0.18$ kg, $m_{sv} = 0.25$ kg,
- pitch of the screw $h = 0.002$ m,
- gear ratio $j = 4$,
- weight of one layer of the fabric $m_{tk} = 0.02$ kg, length of one layer of the fabric $L_t = 0.4$ m, coefficient of friction of the belt to the fabric $\mu_p = 0.3$, the number of layers of fabric in the stack $n_{ilv} = 4$, thickness of compression fabric: $g_t = 0.002$ m,
- elasticity constants of textile: $k_{v1} = k_{h1} := 1 \cdot 10^5$ N/m; $k_{v2} = k_{h2} := 1 \cdot 10^{11}$ N/m³,
- damping coefficients $c_v = c_h = 0.01$ Ns/m;
- number $\varepsilon_v = \varepsilon_h = 18.48$, integration step $\Delta t = 4.51 \cdot 10^{-5}$.

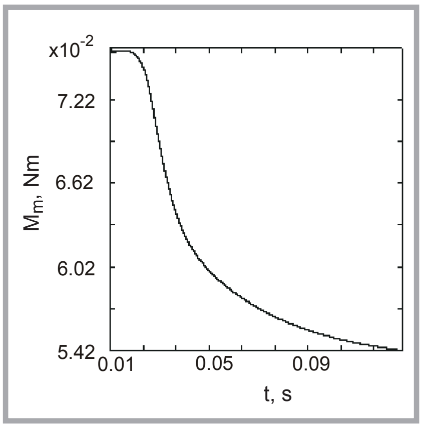

Figure 5. *Time history of the motor torque M_m [Nm] used for driving the rollers leading the belt.*

The motor has been assumed as follows:

- An electric motor for driving the rollers which lead the belt (item 4, Figure 1 in [6]) characterised by: constant voltage $K_b = 0.038$ V/(rad·s), constant torque $K_t = 13.2$ Nm/A, resistance $R = 343$ Ω, inductance $L = 53 \cdot 10^{-3}$ H, supply voltage $e = 25$ V and mass moment of inertia of the rotor $I_{1c} = 5 \cdot 10^{-8}$ kgm².

- The electric motor initiating the vertical movement of the gripper (item 9, Figure 1 in [6]) is characterised by: constant voltage $K_{bv} = 0.038$ V/(rad·s), constant torque $K_{tv} = 0.33$ Nm/A, resistance $R_v = 343$ Ω, inductance $L_v = 53 \cdot 10^{-3}$ H, supply voltage $e_v = 10$ V.

- The electric motor initiating the horizontal movement of the gripper (item 18, Figure 1 in [6]) is characterised by: constant voltage $K_{bh} = 0.038$ V/(rad·s), constant torque $K_{th} = 0.33$ Nm/A, resistance $R_h = 343$ Ω, inductance

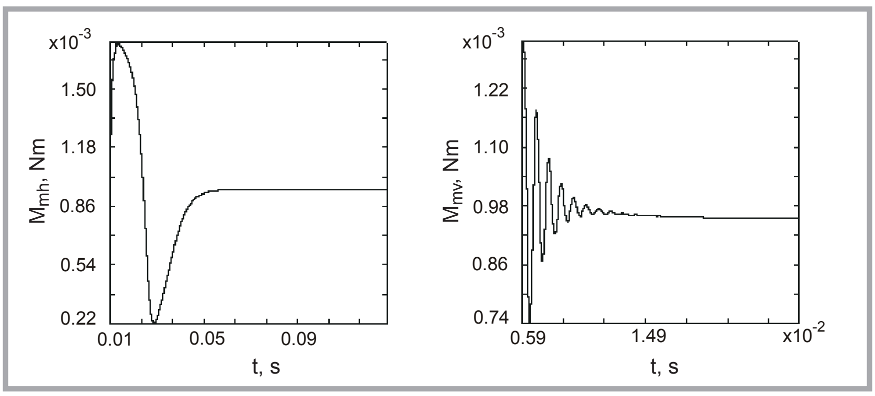

Figure 6. *Time history of the motor torque M_{mh} and M_{mv} in Nm used for initiating the horizontal and vertical movement of the gripper.*

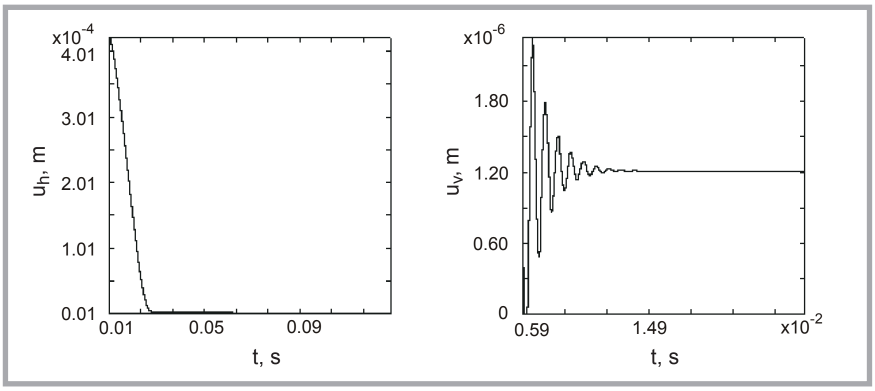

Figure 7. *Time history of the compression of the material u_h and u_v in m.*

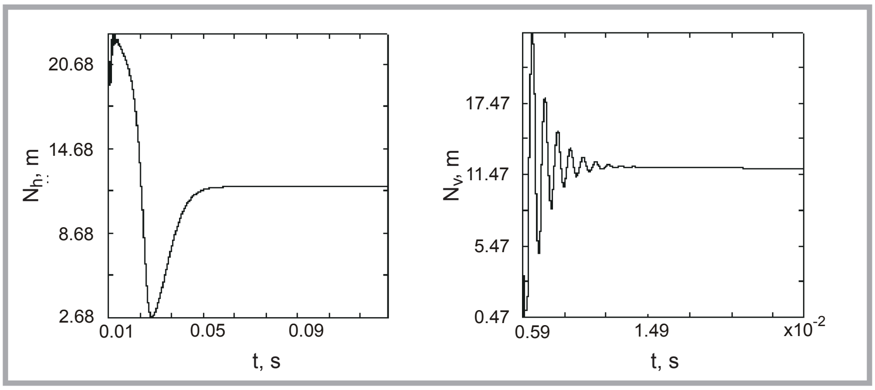

Figure 8. *Time history of the compressing force on the fabric layer located between the gripper and foot N_h in N and of the stack of the fabric N_v in N.*

L_h = $53 \cdot 10^{-3}$ H, supply voltage e_h = 10 V.

Simulation calculations were carried out for various parameters and the results obtained are shown in the graphs (***Figures 5 - 8***).

Graphs (***Figure 8***) show that compressive forces N_h & N_v achieve a maximum value, then decrease and stabilise with time until reaching a constant setpoint value N_{set}.

It has been observed that the stabilisation of parameters up to the value of the force assigned N_{set} takes place sooner for the vertical direction than for the horizontal one, whereas the values of the compressive forces N_v and N_h that cause the deflection of the fabric are close.

These plots illustrate the rheological reaction of the fabric to the gripper operation. Under the influence of the forces the fabric is compressed in the stack u_v between the gripper and foot u_h (***Figure 7***), the values of which, as for forces N_h & N_v stabilise in time and cause compression in the range of 0.05%.

Conclusions

A mathematical model of the gripper separating fabric from a stack has been developed and the phenomena of separation actions of the layer examined. The assumptions made have been confirmed. Thanks to the motors, whose torques are controlled as a function of the size of the pressure, the gripper exerts a sufficient force on the separating fabric to prevent the slipping out of fabric while not exceeding the limit values which may cause damage to the fabric.

A force value N_{zad} was established that the gripper would exert on the separating fabric to prevent it from slipping out while not exceeding the limit force. This is achieved by replacing the clamping spring in appropriate elements of the gripper and having an electric motor whose torque is controlled as a function of the size of the pressure.

The feedback adjusts the value of electromotive forces e_h and e_v, and consequently the values of the current intensity i_h and i_v and driving torques motors M_{mh} and M_{mv} are obtained.

Reducing pressures necessary to maintain the fabric is achieved by increasing the contact surface of the respective elements of the gripper.

Entering the edge of the fabric between the respective elements of the gripper was realised by using the endless belt and then pulling the fabric by the force of friction in the direction of the blockage place where the fold entering between the belt and foot is formed.

Computer programs describing the work of grippers for textiles allow analysis of the behavior of the system, which shortens the design process of the device. Modelling studies showed that there is a possibility to choose relevant parameters of these mechanisms.

The model of the gripper developed, which is characterized by an increased working surface, was granted a patent as an invention on 31.01.2008 [9].

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