24th International Conference
ENGINEERING MECHANICS 2018
Svratka, Czech Republic, May 14 –17, 2018
Paper #328, pp. 753–756, doi: 10.21495/91-8-753

GENERATION OF A MOTION FUNCTION FOR OPTIMAL NEEDLE RACK MOTION OF A CAM EL WEAVING MACHINE

M. Sivčák *

Abstract: *This paper describes the creation of a new motion function for the needle rack of the CAM EL weaving machine. The shape of the acceleration motion function curve is defined by a set of seven control points. Derived equations have been used in the creation of a computer program, which simulates the motion of the needle rack. Using the newly designed motion function, a significant reduction of the maximum torque of the actuator has been achieved.*

Keywords: weaving machine, motion function, optimization of motion, kinematics, approximation

1. Introduction

CAM-EL is a weaving machine for the manufacture of fabrics produced by VUTS. An updated version of this machine which is expected to increase productivity by 25% is currently being developed. Part of the weaving machine is the needle drive mechanism that will be addressed in this paper (Figure 1).

Analysis of the model of the needle assembly from the servomotor to the actual needle showed that even a small change in the stroke dependence $u(t)$ has a significant impact on the size of the maximum torque of the actuator $M = M(u, \dot{u}, \ddot{u})$. That is why we want to optimize the existing dependency ratio $u(t)$. We require that the required driving torque is minimal and at the same time keep the machine running smoothly without the need for unnecessary impacts (Jirásko, 2015), so that the stroke is sufficiently smooth (Koloc, 1988).

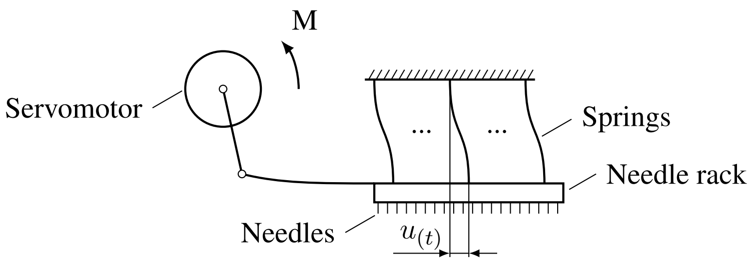

Fig. 1: The needle rack system

A function made up of fifth order polynomials with continuous derivatives to the 5th order will be considered sufficiently smooth. For the design of the lifting dependence, it is preferable to approximate its second time derivative (acceleration) which is represented by polynomials of the third order with condition of connection in the first and second derivatives by cubic spline.

We therefore implement an approximation function $f(x)$ which is an accelerated image $\ddot{u}$, defined on the interval $x \in \langle 0, 1\rangle$. We also choose $f(x)$ as symmetric to $[0.5, 0]$. By normalizing the approximate function so that its second integral at the end of the interval is equal to 1, we obtain the unit function of the stroke $u^{\circ}(x)$. Coefficients describing this function can be easily used to program the control unit of the actuator. For future use, the shape of an approximation function is generated on the basis of the selected definition points by which $f(x)$ passes. These points will later be generated automatically by optimization algorithms.

* Ing. Michal Sivčák, Ph.D.: Technical University of Liberec, Studentská 1402/2; 461 17, Liberec; CZ, michal.sivcak@tul.cz

2. Definition of the definition points and the approximation function

All points of the set defined on the interval $\langle 0, 0.5\rangle$ in direction of x and the interval $\langle 0, 1\rangle$ in direction of y will be called definition points, see Fig. 1. Each of these points has coordinates $[X_j, Y_j]$, where $j = 1..N$ denotes the order of the point given its distance from origin in direction of the x axis. For practical reasons, count of the definition points was chosen to be $N = 7$.

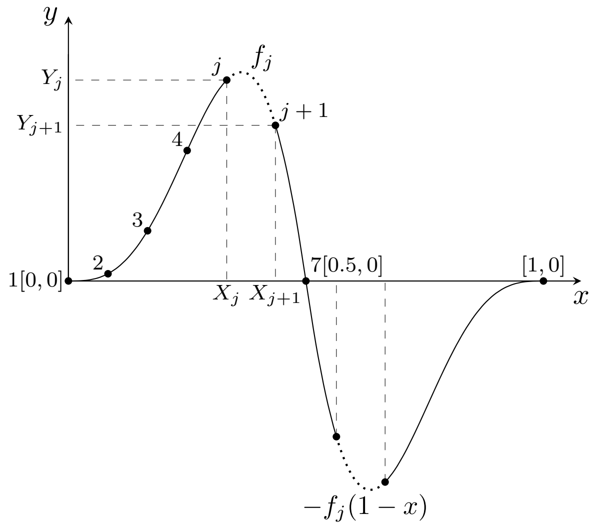

Fig. 2: Definition points

The function $f(x)$ must pass through points $[0, 0]$, $[0.5, 0]$ and $[1, 0]$. Considering the above mentioned symmetry, we will, until further notice, focus on the left side of the function $f(x)$, therefore $x = \langle 0, 0.5\rangle$.

3. Approximation function

A function passing through an interval j can be written as

$$f_j(x) = b_{1,j} + b_{2,j}x + b_{3,j}x^2 + b_{4,j}x^3,$$

where $b_{k,j}$ are unknown constants.

For the description of the function $f(x)$ it is necessary to find all the constants $b_{k,j}$, where $k = 1..4$ and $j = 1..N-1 = 1..6$. This totals to 24 unknown values $b_{k,j}$. By using standard tools for approximation by cubic spline it is possible to determine the coefficients. The only unknown is the estimate of the derivation in the centre of interval D.

The point nr. 7 is the point of symmetry of the function $f(x)$. We fit third degree polynomial to the points 5, 6 and their symmetrical images.

$$g(x) = B_1 + B_2x + B_3x^2 + B_4x^3,$$

where B_1, B_2, B_3 a B_4 are unknown constants. The desired value D can be expressed as

$$D = \left.\frac{\mathrm{d}g(x)}{\mathrm{d}x}\right|_{x=0.5}.$$

Because $g(x)$ must pass through the above mentioned points, it is possible to write the system of four equations

$$\begin{aligned} g(X_5) &= Y_5 \\ g(X_6) &= Y_6 \\ g(1-X_5) &= -Y_5 \\ g(1-X_6) &= -Y_6. \end{aligned}$$

The solution are constants $B_1, \ldots, B_4$. As we now know the whole function $g(x)$, using $B_1..B_4$ derivative of this function at point $[0.5, 0]$ can be expressed as

$$\left.\frac{\mathrm{d}g\left(x\right)}{\mathrm{d}x}\right|_{x=0.5} = \frac{8\,X_5{}^3Y_6 - 8\,X_6{}^3Y_5 - 12\,X_5{}^2Y_6 + 12\,X_6{}^2Y_5 + 6\,X_5Y_6 - 6\,X_6Y_5 + Y_5 - Y_6}{2\left(2\,X_6 - 1\right)\left(2\,X_5{}^3 - 2\,X_5X_6{}^2 - 3\,X_5{}^2 + 2\,X_5X_6 + X_6{}^2 + X_5 - X_6\right)}.$$

4. Scale of the amplitude

The approximation function $f(x)$ is an input for derivation of unit motion function $u^\circ(x)$, acceleration of which has the same form as $f(x)$. For the unit motion function, the following condition must be met

$$u^\circ(0) = 0 \wedge u^\circ(1) = 1.$$

Define an approximated velocity F_j^I and an approximated motion F_j^{II} on j^{th} interval using known function $f_j\left(x\right)$

$$f_j\left(x\right) = \frac{\mathrm{d}F_j^I}{\mathrm{d}x} \quad \text{a} \quad F_j^I = \frac{\mathrm{d}F_j^{II}}{\mathrm{d}x}.$$

Using separation of variables on the first expression and then integrating over the full j^{th} interval, it is possible to derive value of the velocity at the end of the j^{th} interval

$$F_j^I(x_{j+1}) = F_j^I(x_j) + \int\limits_{x_j}^{x_{j+1}} f_j\left(x\right)\mathrm{d}x.$$

It is obvious, that the velocity at the end of the interval depends not only on function $f_j\left(x\right)$, but also on the velocity at the beginning of the interval $F_j^I(x_j)$. Choose zero velocity for the first point $[0, 0]$, i.e. $F_1^I(0) = 0$. In an analogous manner, we derive the function of velocity inside the j^{th} interval.

$$F_j^I(x) = F_j^I(x_j) + \int\limits_{x_j}^{x} f_j\left(x\right)\mathrm{d}x.$$

Since the function $f(x)$ is symmetric and velocity at the beginning and at the end of the process is equal to zero, it is sufficient to address only one half of the interval.

Separating and subsequent integrating the expression

$$F_j^I = \frac{\mathrm{d}F_j^{II}}{\mathrm{d}x}$$

over the full j^{th} interval, we derive expressions for calculation of deflection at the end of the interval

$$F_j^{II}(x_{j+1}) = F_j^{II}(x_j) + \int\limits_{x_j}^{x_{j+1}} F_j^I\left(x\right)\mathrm{d}x.$$

and integrating from the beginning of the j^{th} interval to a general position inside of this interval, we get the function of the deflection

$$F_j^{II}(x) = F_j^{II}(x_j) + \int\limits_{x_j}^{x} F_j^I\left(x\right)\mathrm{d}x.$$

For the first point, set the deflection to zero

$$F_1^{II}(0) = 0.$$

With respect to the symmetry and the set initial conditions, the trajectory in the middle of the interval $F_6^{II}(0.5)$ is exactly equal one half of the total trajectory

$$F_{12}^{II}(1) = 2F_6^{II}(0.5)$$

and therefore it is sufficient to integrate only on the interval $x = 0..0.5$. After performing all of the operations, we get one half of the motion at the acceleration $f(x)$. This motion depends only on the definition points and the already calculated values $b_{k,j}$.

The number $F_{12}^{II}(1)$ is the demanded value of the scale between $F^{II}(x)$ and the unit motion $u^\circ(x)$ and it is valid given that

$$u^\circ(x) = \frac{1}{F_{12}^{II}(1)} F^{II}(x).$$

5. Practical use

All quantities are derived strictly analytically and they react to the change of the point very quickly. This is suitable for future usage in automatic task optimization and inserted into the machine control program. Using the above mentioned knowledge, new software has been developed, which allows an easy manual manipulation with the definition points and immediately shows the necessary moment. It also enables the behavior of the function of deflection to be displayed, as well as velocity, acceleration and power. A great advantage of the newly designed software is its capability to export the coefficients $b_{k,j}$ into a text file. These files can be directly used for setting the control circuit of the servomotor. Comparison of the original solutions and the newly found solutions are shown in the Table 1 and Figure 3.

Tab. 1: Comparison of maximal moments of the servomotor

main shaft speed	max. original moment	new max. moment
600 [1/min]	5[Nm]	2.2[Nm]
750 [1/min]	9.2[Nm]	4.2[Nm]

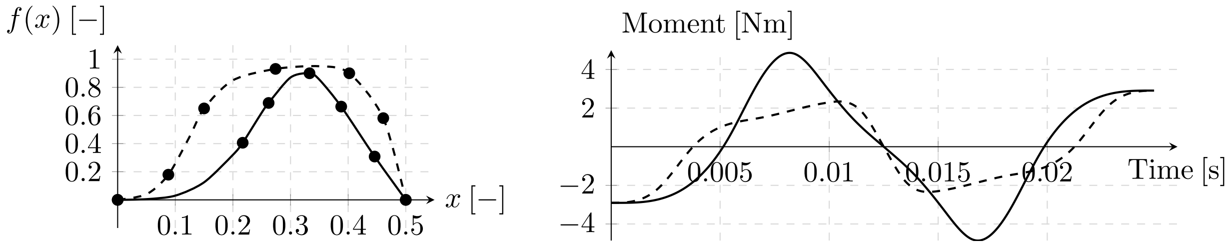

Fig. 3: Original (solid line) and new (dashed line) creation curve, expressed using definition points (on the left) and corresponding moment for the main shaft speed 600*[1/min] (on the right).*

Acknowledgments

This publication was written at the Technical University of Liberec, Faculty of Mechanical Engineering with the support of the Institutional Endowment for the Long Term Conceptual Development of Research Institutes, as provided by the Ministry of Education, Youth and Sports of the Czech Republic in the year 2017.

References

Jirásko, P., et al. (2015), *Mechatronika pohonů pracovních členů mechanismů*, VÚTS a.s., Liberec.

Koloc, Z., Václavík, M. (1988), *Vačkové mechanismy*, SNTL, Praha.