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Some of the aspects of decision design in development of the intelligent wire casting machine

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Abstract

The process of microwire casting can be one of the methods of nanotechnology and advanced materials. The objective of this paper is to discuss the problem of decision design in the development of an intelligent machine for casting of microwire. The paper presents the decision making structure and describes its elements for microwire production based on direct casting from the melt. The most important element of the decision making structure is given by the drop model. According to this, important details of the model are discussed. The results presented here are intended to be used in the decision support system design for building of the intelligent casting machine.

1 Introduction

It is a fact, that innovative technologies are the engines of a competitive economics. Obviously, industrial technologies are very important for such economics. It is well-known, that most of modern technological processes are automated. But there are industrial applications where human presence is essential given the complexity of the technologies. For instance, in continuous casting of glass-coated microwires ([3]) it is not possible to dispense with manual intervention because of high complexity of the casting process. Such technologies require online recognition of the process and online decision making. In this context, it is important the development of advanced techniques in order to optimize industrial information systems with human in the loop. Such a system is concerned with all personnel, equipment, software, processes and knowledge to provide data for decision making structure. This structure should provide how the system will evolve, how far the best performance is, what actions should be undertaken.

The paper discusses the problem of decision design in the development of the intelligent wire casting machine. Some of the aspects of online analysis and decision making problem in continuous casting of glass-coated microwires are discussed in ([4]). Our purpose is to develop some of the preliminary results presented in ([4]). Next section describes the structure of decision making for the process of microwire production based on direct casting from the melt. The most important element of the decision making structure is given by the drop model. According to this, the last section develops the subject of the drop model.

2 Decision design problem in production of microwires

First of all, let us briefly describe the fabrication of glass-coated microwires. Glass-coated microwires are manufactured by means of a modified Taylor-Ulitovsky process based on direct casting from the melt ([3]). A rod of the alloy of desired composition is put into a glass tube and placed within a high frequency inductor heater. The alloy is heated up to its melting point, forming a droplet. While the metal melts, the portion of the glass tube adjacent to the melting metal softens, enveloping the metal droplet. A glass capillary is then drawn from the softened glass portion and wound on a rotating bobbin. At suitable drawing conditions, the molten metal fills the glass capillary and a microwire is thus formed where the metal core is completely coated by a glass shell. The casting process is carried out at a temperature that will melt the alloy and soften the glass tube. The final microwire structure is formed by water-cooling to obtain a metallic core in amorphous or non crystalline state. After passing through the cooling water, the microwire comes to spool of a receiving mechanism.

In the area of microwire fabrication a lot of human experience and knowledge has been accumulated. We consider that this fact should be used to optimize the production of microwires at the system level. The process of decision making represents one of the main problems in continuous casting of glass-coated microwires. In the casting of glass-coated microwires, the human operator plays the role of decision maker. The figure 1 illustrates the structure of decision making for the process of microwire production.

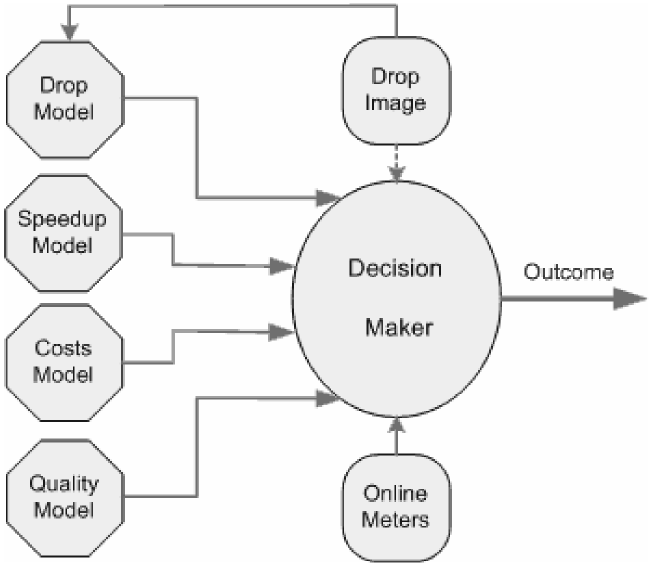


Figure 1. *Structure of decision making.*

As it can be seen from the figure 1, the structure of decision making consists of the following elements:

- Drop model.
- Speed up model.
- Costs model.
- Quality model.
- Drop image sensor.
- Online meters.
- Decision maker.

The process of decision making requires us to analyze a decision according to quality, costs, and speed up of wire production. The quality model must take into account the quality of the alloy and glass tube, the quality of the online meters (sensors) and other measurement equipment. Besides, a coefficient of repeatability of the measurement results must be introduced into the quality model. The costs must include the alloy, glass tube, measurement equipment, and human costs. The speed up model reflects the speed up of the microwire production. It is referred to a set of values for the rod, glass tube, and spool speed.

It is evident that the quality of final product, the costs of production, and the speed up of production represent evaluative criteria in microwire production. On the other hand, all these factors are interconnected. As it was mention above, the human operator plays the role of decision maker. Therefore, the objective of the operator is to evaluate online the quality of wire (its parameters, such as the diameter) and follow a course of action to satisfy the above criteria.

It is necessary to say that a highly skilled operator can make good online decisions over the casting process only using the information captured by his eyes. The information is with respect to color and shape of the drop. Therefore, the machine vision techniques should be quite suitable for the process of wire casting. Machine vision ([2]) is successfully used today in industrial applications. This approach has become a vital component in the design of advanced systems because it provides a means of maintaining control of quality during manufacture. For this reason, the structure on the figure 2 contains a drop image sensor. The last one is connected as the input to the model of the drop, which represents one of the most important elements of decision making structure. Such a model must play a major role in the decision support system design for building of the intelligent casting machine for microwire production. Next section develops the subject of the drop model.

3 Drop model

The main ideas of the drop model presented here were developed and described in ([5]). Our purpose was to construct a drop model, which will be useful to explain and predict behavior within the process of casting. Farther, it will show in detail that the interpolation polynomial in the Lagrange form can serve the purpose.

More precisely, we have to find a function that describes the shape of the drop. It should be mentioned that the drop is quite symmetrical under normal working conditions. Moreover, it was established from the analysis of a lot of experimental data that the upper part of the drop can be ignored. Therefore, it is enough to consider the right/left shape of the drop due to its symmetry.

It was observed that during casting process the shape of the drop is changing. Besides, because of both the geometry of inductive heater and some other factors the shape of the drop may vary from one casting machine to other.

So, we are looking for a model that will take into account current features of the casting process and will approximate online the working shape of the drop. On the other hand, such a model should allow us to estimate the geometry of the metal-filled capillary and predict the diameter of microwire. In order to meet these requirements, we decided to extract a given set of data points from the shape at a time. Then, the current shape must be interpolated. In this way we can obtain the function, which approximates online the shape. This function may offer us the information about the geometry of capillary.

Let us consider the interpolation polynomial in the Lagrange form.

Given a fixed interval $I \in R$ and a set of $(p+1)$ interpolation points $x_0<x_1<x_2<\ldots<x_p$ on I, a function can be defined $f : I \to R$. To interpolate the function f, we define the values y_i as $y_i = f(x_i)$, for $0 \le i \le p$.

The points y_i are the values of interpolation. We must use the unique interpolation polynomial of degree $P \le p$, which verifies $P(x_i)=y_i$, for $0 \le i \le p$ and $f(x) \cong P(x)$ for any $x \in I$.

Let L_j, $0 \le j \le p$, be the Lagrange basis polynomials

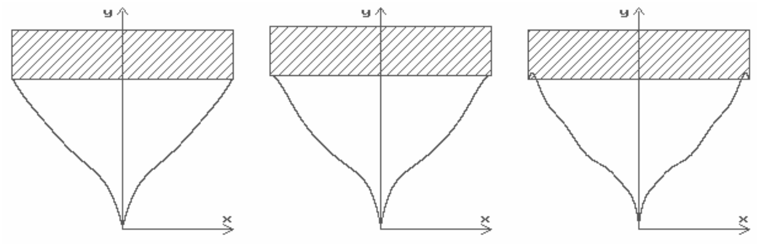
$$L_j(x) = \frac{(x - x_0)...(x - x_{j-1})(x - x_{j+1})...(x - x_p)}{(x_j - x_0)...(x_j - x_{j-1})(x_j - x_{j+1})...(x_j - x_p)}. \quad (1)$$

Then, the interpolation polynomial in the Lagrange *P(x)*, associated to the set of data points is

$$P(x) = \sum_{j=0}^{p} y_j L_j(x). \quad (2)$$

It should be noted that the Lagrange basis polynomials L_j given by formula (1) depend only on the interpolation points selected, and do not require any auxiliary restrictions. This fact represents an advantage in using the interpolation polynomial in the Lagrange form (2) to approximate the shape of the drop.

To obtain the information about the optimum number of points to be used by the interpolation polynomial in the Lagrange, a comparative experimental analysis was carried out. During this experimental study we have established that when seven interpolation points are extracted from the shape a satisfactory approximation of the droplet shape is occurring. The figure 2 presents the experimental result of the interpolation when six (figure 2, a), seven (figure 2, b), and nine (figure 2, c) interpolation points are extracted online from the shape of the drop during casting.



a) b) c)

Figure 2. *Comparative result of the shape interpolation.*

Given a set of seven ($p = 6$) online data points (x_0,y_0), (x_1,y_1),...,(x_6,y_6) where no two x_j are the same, the Lagrange basis polynomials can be written. Then, the Lagrange basis polynomials can be easily calculated by means of the recursive functions. The figure 3 shows the result of the online approximation of the drop shape, when seven interpolation points are extracted.

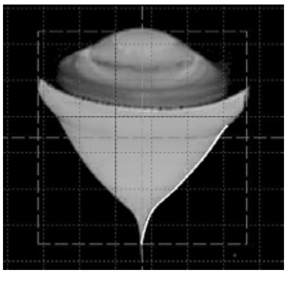


Figure 3. *Online approximation of the drop shape.*

As it can be seen from the figure 3, the drop shape follows a curve line. The curve line changes from being convex to concave. The interpolated online curve (see the white line on figure 3) does the same and follows the drop shape. The analysis of a lot of experimental data confirms the latter. We can conclude that the approximation based on the interpolation polynomial in the Lagrange form may be used for the construction and using the drop model in the decision making structure, which was described in the previous section.

Another important question now is how can we extract the information about the geometry of the metal-filled capillary? A possible way is illustrated in figure 4.

In our opinion, at first, it is necessary to determine the inflection point (IP) on the interpolated online curve. In order to calculate the location of the inflection point, it is necessary to find the second order derivative of the interpolation polynomial in the Lagrange form.
It can be shown that the second derivative takes the form:

$$P^{//}(x)=\sum_{j=0}^{p}\Big[\ \frac{y_j}{\prod\limits_{i=0;i\neq j}^{p}(x_j-x_i)}\sum_{\substack{i_1=0\\ i_1\neq j}}^{p}\ \sum_{\substack{i_2=0\\ i_2\neq j\\ i_2\neq i_1}}^{p}\ \prod_{\substack{i=0\\ i\neq j\\ i\neq i_1\\ i\neq i_2}}^{p}(x-x_i)\ \Big]. \tag{3}$$

The second order derivative (3) equals zero in the inflection point. Hence, its location can be calculated online.

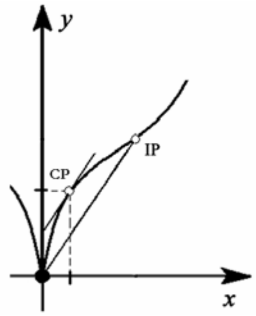


Figure 4. *Operating point of the metal-filled capillary.*

After that, another point may be determined. We call it the capillary or operating point (CP on figure 4). The latter should be very important because it seems to be the entry point of the metal-filled capillary. It is easy to observe that the point CP may be located by means of well-known Lagrange's formula:

$$f^{/}(x_0)=\frac{f(b)-f(a)}{b-a}\ ,\ x_0\in(a,b). \tag{4}$$

In order to determine the location of the capillary point, the interval [0, *IP*] must be considered (see figure 4).
The above model must allow us to estimate online the geometry of capillary at each time during casting. To obtain online information about the drop, its image must be processed in real-time to track the geometrical and color features of the drop. For these reason, a software application was developed. To capture and process the image the application uses the DirectX libraries. This software application provide us with the following online information: geometrical characteristics and position of the drop during casting, the color histogram, YUV/RGB components, and the color map of the drop.
The process of the drop identification, involves image segmentation and edge detection. Segmentation involves separating the image into regions. Our application uses thresholding to determine the region of the drop area by identifying of four boundary points. Then, edge detection is performed. There are many ways to perform edge detection. We tried different algorithms to detect the drop edge. Our experiments showed that the Canny algorithm ([1]) provides the best results.
The last step is dealing with the approximation of the drop shape and the localization of the capillary (operating) point, according to the model presented above. In this context, the interpolation points are calculated as follows.
At first, a lot of points are extracted from the drop shape. Those points are integer numbers. Then a set of five reference points is determined based on extracted points, acording to the expression:

$$P_r = k_1 \bullet P_{j-2} + k_2 \bullet P_{j-1} + k_3 \bullet P_j + k_4 \bullet P_{j+1} + k_5 \bullet P_{j+2}, \qquad (5)$$

where $j = 5(r-1)+3$, for $1 \le r \le 5$, and $k_1 = k_5 = 1$, $k_2 = k_4 = 2$, $k_3 = 3$. The expression (5) and the values of coefficients were obtained experimentally. It should be noted, that the coordinates of these five references are numbers in floating point format. Given the set of five reference points as well as two points at the ends of the drop shape (white circles in the figure 5), the Lagrange basis polynomials can be written and calculated.

Then the point of inflection and the capillary point location are determined by means of relations (3) and (4) respectively.

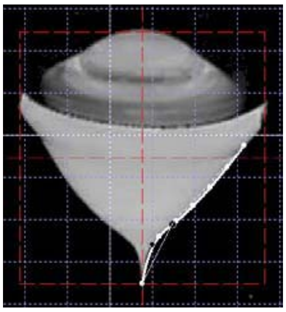


Figure 5. *Online calculation of the capillary point location.*

Figure 5 shows the calculated online location for the inflection point and capillary point (black points in the figure 5) during casting.

As it was mentioned in the introduction, we aim the development of advanced techniques for the optimization of industrial information systems with human in the loop. The proposed approach and methods must help the human operator in taking optimal online decisions during microwire casting.

In conclusion, we want to mention that the results presented above are intended to be used in the decision support system design for the microwire casting machines in order to provide data and knowledge for decision making.

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