DETERMINATION OF THE CAPACITY OF A CONTINUOUS TRANSPORT SYSTEM USING SPLINE TYPE INTERPOLATION

FLORIN DUMITRU POPESCU[1], ANDREI ANDRAȘ[2], ILDIKO KERTESZ BRÎNAȘ[3]

Abstract: The control of the functioning of the continuous transport system also implies the knowledge of the technological process by monitoring the flow of transported material. In this aspect, one of the classical methods used is weighing the material, which due to the limited reliability, has not been generalized. The paper proposes a solution to this problem by using an unconventional methods, that ensure reliability, accuracy and the possibility of integration in the general monitoring system. Permanent measurement, at equal time intervals, of the cross-section of the material carried by the conveyor belts and the instantaneous transport speed, leads to the determination of the volume transported. Based on the average density of transported material, the capacity of the continuous transport system can be determined.

Keywords: continuous transport, transport capacity, interpolation, spline,

1. THE PROPOSED SOLUTION

Permanent measurement of the volume of moving material in a continuous transport system, implies knowing the shape of the conveyed material cross-section at a given time and the instantaneous speed of the conveyor belt (figure 1).

Figure 2 shows details of the proposed solution. The shape of the cross-section of conveyed material (2) can be approximated by interpolation based on the measured height of the pile at the discharge end (1) of the transporter, using ultrasonic transducers (T_1 ... T_9) mounted on a frame (3). The instantaneous speed is determined by measuring the output voltage of a tach-generator (TG) driven by the transporter.

[2] *Prof, Eng. Ph.D. , University of Petroșani, fpopescu@gmail.com*
[3] *Lecturer, Eng. Ph.D., University of Petroșani, andrei.andraș@gmail.com*
[4] *Assistant, Eng. Ph.D., University of Petroșani*

These measurements are the input data (voltages) that are read by a computer, using a data acquisition board or a microcontroller. The volume determination is done by integration of the approximate shape of the section of transported material. Based on the median density of the material, the mass flow rate can also be determined.

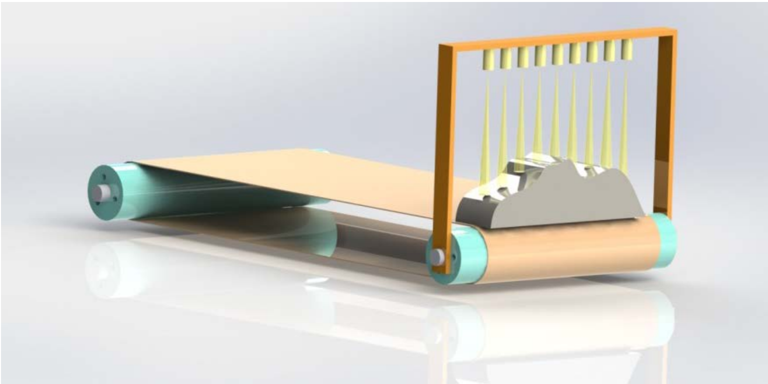

Fig.1 The proposed solution

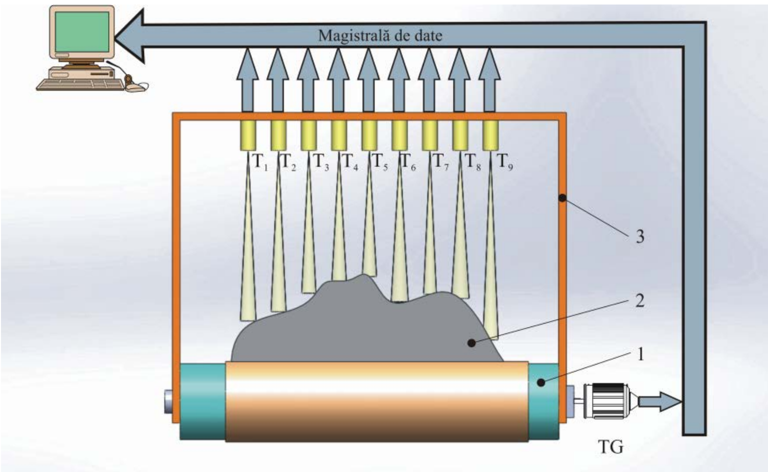

Fig.2 Detailed view of the proposed solution

In order to be able to integrate the shape of the section of conveyed material for the calculation of the cross-section area, it is necessary to measure the material height at the discharge end in several points and to approximate the shape by numerical interpolation methods.

Interpolation is a method of estimation for obtaining a simple approximate function, using discrete set of known values acquired via experimental measurements, for the function whose analytical expression is either unknown nor can be determined by analytical means.

For a function *f*, if we know the values corresponding to the argument *x*: $f(x_0)$, $f(x_1)$, ..., $f(x_n)$, using these values, we define another simpler function for calculations (derivation or integration), a function which at given points x_0, x_1, ..., x_n has the same values as the initial function, while at other different points it can approximate with a sufficient degree of precision the values of the initial function. Often, this function can be a polynomial, because at small intervals of argument *x* the function *f(x)* can be well approximated by the curves whose analytical representation are polynomials.

2. SPLINE FUNCTIONS

Spline-type interpolation is solved using polynomial functions, in subintervals of the range of defining the given function. Considering $a = x_1 < x_2 < ... < x_n = b$ as a division of the interval *[a, b]*, a polynomial spline function of degree *p* with the nodes at points x_i $i = 1, ... , n$ is a function *S(x)* with the following properties:

• for each subinterval $[x_i\ x_{i+1}]$, *i=1, ... , n-1,* the function *S(x)* is a polynomial of degree *p*;

• *S(x)* and its first *p-1* derivatives are continuous over the interval *[a, b]*.

In order to present this interpolation method, the cubic spline functions will be used, determining the number of parameters that characterize a cubic spline function.

Thus corresponding to the *n-1* subintervals we have *n-1* third degree polynomials characterized by 4 parameters each, so in total we have to determine *4n-4* parameters.

The fact that the function *S* and its derivatives S' and S'' must be continuous in the inner nodes x_i *(i=2, ... , n-1)* gives us $3 \cdot (n-2)$ conditions. At the same time the requirement that $S(x_i) = y_i$ for each node imposes another *n* conditions, so in total *4n-6* conditions. Two more additional conditions are needed to uniquely determine the cubic spline function. Thus we can put the condition that at the end of the interpolation interval we have turning points, which means that:

$$S''(x_1) = S''(x_n) = 0 \tag{1}$$

and in this way we obtain the natural cubic spline function because the boundary conditions (2.12) are considered natural.

The construction of a cubic spline function is a simple and stable numerical process. In this scope a program in C language was written, that allows the approximation of a cross-section shape through spline functions.

3. VALIDATION OF THE RESULTS

In order to evaluate the accuracy of the results obtained, two calculation variants were considered. The first variant is based on a cross section corresponding to a uniform placement of the material on the conveyor belt in the area of the discharge point. The considered values measured (in relative units) are presented in table 1.

Table 1 **Measured values for variant 1 (uniform placement)**

x	0	1	2	3	4	5	6
y	0	1	1,5	2	1,5	1	0

The profile as determined by linear interpolation is shown in figure 3.

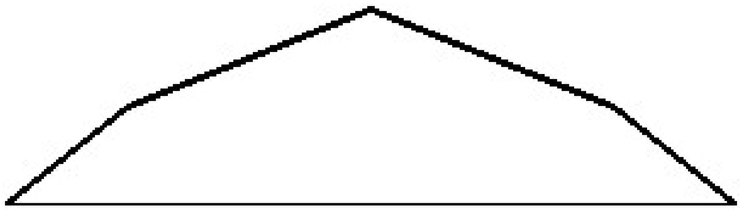

Fig. 3 Profile corresponding to linear interpolation (variant 1)

By using spline functions the profile shown in figure 4 was obtained:

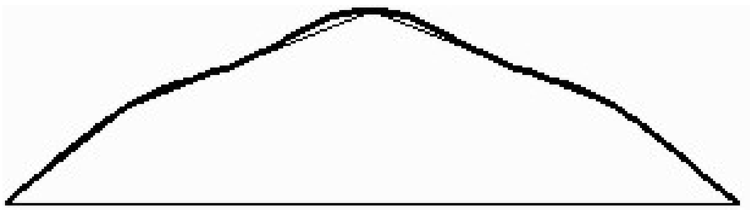

Fig. 4 Profile corresponding to spline function interpolation (variant 1)

The second variant is based on a cross section corresponding to an uneven placement of the material on the conveyor belt in the area of the point of discharge. As in the previous case, in table 2 the relative values for x and y are presented:

Table 2 **Measured values for variant 2 (uneven placement)**

x	0	1	2	3	4	5	6
y	0	1	2,5	1	1,5	1	0

For this case, the determined shape using linear interpolation is presented in figure 5:

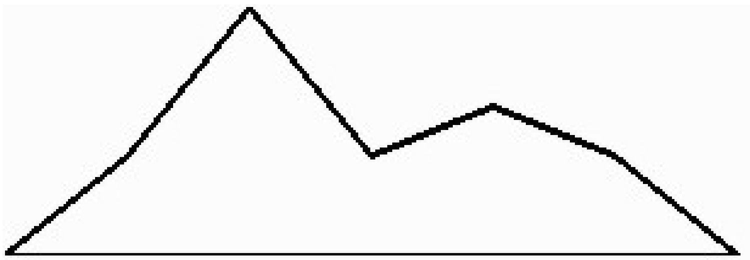

Fig. 5 Profile corresponding to linear interpolation (variant 2):

Using the spline function interpolation as approximated by the written C program, the obtained shape is shown in figure 6:

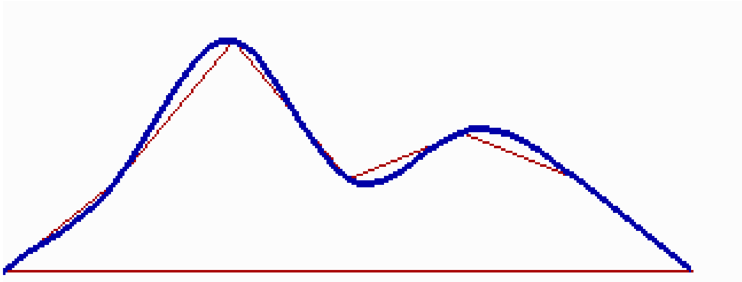

Fig. 6 Profile corresponding to spline function interpolation based on C program approximation (variant 2):

The approximation method used in the program written in C language for spline functions was verified by plotting - for the values in Table 2 – the linear interpolation and the interpolation by cubic polynomials (splines), for each considered interval, using SolidWorks. The result of this verification of the approximation is shown in figure 7.

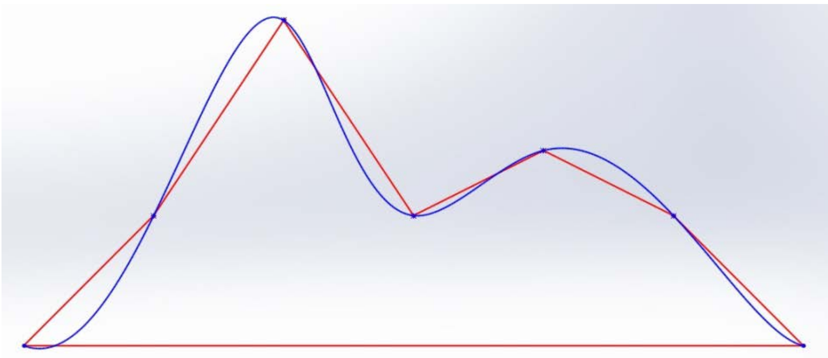

Fig. 7 Results obtained in SolidWorks for verification

By analyzing and comparing the results obtained by using the application written in C language with those obtained in SolidWorks, the approximation of the profile using the written C program generates correct values.

4. APPROXIMATE CALCULATION OF THE VOLUME OF TRANSPORTED MATERIAL

Based on the premise that at equal intervals a computer reads data from the tach-generator, so the linear speed of the conveyor belt is known, and also the transducers provide the distance to the top of the conveyed material in the measuring area (Figure 8).

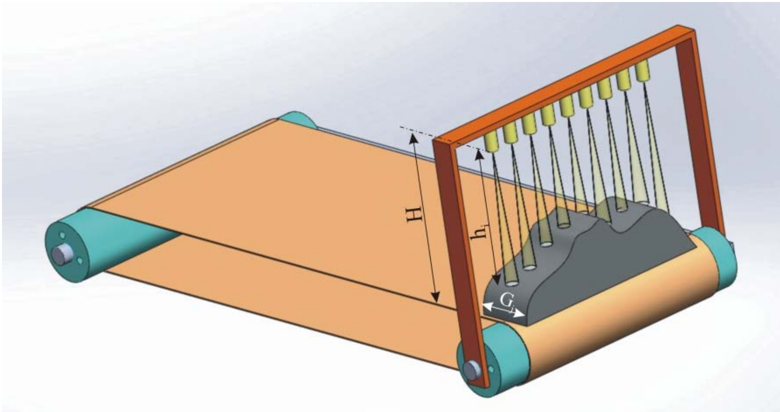

Fig. 8 Conveyed material volume calculation

The thickness G of the material can be determined using the equation:

$$G_j = v_j \cdot \Delta t \tag{2}$$

where: v_j – represents the speed measured by the tach-generator;
Δt – is the time interval at which the readings are done.

The height of the conveyed material profile corresponding to each ultrasonic transducer will be:

$$h_{tj} = H - h_j \tag{3}$$

where: H – is the distance between the transducer and the conveyor belt;
h_j – is the distance to the top of the material pile, measured by each transducer at a certain reading.

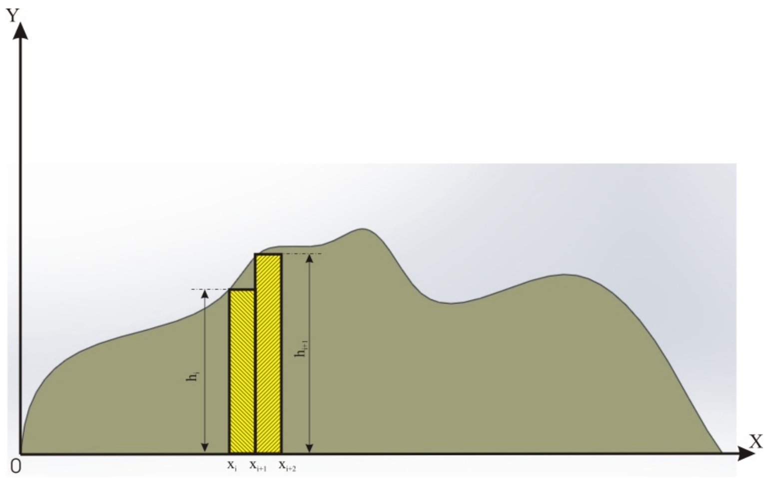

Fig.9 Approximated profile using slpline type interpolation for one reading

Based on the readings of the ultrasonic transducers and after the spline type interpolation, the profile (shape) shown in figure 9 is approximated.

For two adjacent transducers, using the spline function interpolation method, a polynomial of degree 3 will be determined, so that for the width corresponding to each transducer reading, the height of the material profile at any point of the *x*-axis can be calculated. Thus the intermediate areas will be given by the equations:

$$\begin{aligned} A_i &= (x_{i+1} - x_i) \cdot h_i \\ A_{i+1} &= (x_{i+2} - x_{i+1}) \cdot h_{i+1} \end{aligned} \tag{4}$$

The total area of the profile section at a particular interrogation will have the expression:

$$A = \sum_{i=1}^{n} A_i = \sum_{i=1}^{n} (x_{i+1} - x_i) \cdot h_i \tag{5}$$

The approximate volume of material transported for one interrogation will be:

$$V_j = G_j \cdot A = G_j \cdot \sum_{i=1}^{n} A_i = G_j \cdot \sum_{i=1}^{n} (x_{i+1} - x_i) \cdot h_i = v_j \cdot \Delta t \cdot \sum_{i=1}^{n} (x_{i+1} - x_i) \cdot h_i \tag{6}$$

Finally, the total volume of material transported in a time interval T will be:

$$V = \sum_{j=0}^{N_{\text{int}}} \left(v_j \cdot \Delta t \cdot \sum_{i=1}^{n} (x_{i+1} - x_i) \cdot h_i \right) \tag{7}$$

Where $N_{in\ t}$ represents the number of interrogations performed in the time interval *0 ... T*. Given that we have assumed that the queries are made at equal time intervals (Δt) the expression of this value will be:

$$N_{\text{int}} = \frac{T}{\Delta t} \tag{8}$$

5. CONCLUSIONS

The problem of determining the transport capacity, respectively of the flow, of a continuous transport system requires several approaches. In this respect, we have analyzed the possibilities of determining the transport capacities for a system composed of a number of conveyors that work in a certain configuration.

The calculation of the volume of transported material implies the approximation of the profile by interpolation and the determination of the instantaneous speed. The comparative study of the interpolation methods has shown the advantages of using cubic spline functions. Because the monitoring is done using self-written programs in real time, we have verified the correctness of the results by comparing the Lagrange polynomial interpolation with the result obtained in Microsoft Excel and the spline function interpolation with the results obtained in SolidWorks.

The experimental investigations carried out allows to conclude that it is possible to determine the height of the profile of conveyed material in the area of the discharge end of a conveyor belt using ultrasonic transducers.

The actual calculation of the volume is done based on input data gathered using a data acquisition card and sent to a computer. Taking into account the speed of variation in time of the monitored parameters (profile shape and the transport speed) it can be stated that the written C program can provide both instantaneous and global information regarding both the volume of transported material and the corresponding mass flow rate.

The proposed method also allows the determination of the transported material density, knowing the total mass transported and the corresponding volume, for one work shift. If the transported material is coal (in the case of mining operations in the Jiu Valley), based on the density, useful information regarding the quantity of waste ca be determined.

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