*ENGINEERING TRANSACTIONS* • *Enging. Trans.* • 39, 3-4, 561-570, 1991
Polish Academy of Sciences • Institute of Fundamental Technological Research

# PARAMETRIC IDENTIFICATION OF A MODEL OF THE UNLOADING PROCESS OF AN UNIVERSAL TRAILER

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Parametric identification of a certain discrete, one-dimensional, nonlinear mathematical model is presented in the paper; concerning the process of unloading of an universal agricultural trailer. The identification problem is formulated as a problem of numerical minimization and solved by means of the COMPLEX algorithm. The numerical results obtained are illustrated by the example of hard coal unloading from the RT-1/3.5 type trailer.

## 1. INTRODUCTION

The construction of modern universal agricultural trailer (with a floor conveyor) requires an accurate analysis of the unloading process with special consideration of the power consumption of the process. No universal method of such a research has been proposed as yet. The scarce attempts which were made, in the domain of theoretical methods [8] in particular, show that there are difficulties in determining the real values of the parameters concerning friction. Thus an essential element of the computer simulation of an unloading process is the determination of the parameters of the mathematical model of the process considered. After separating in that model some elementary physical phenomena (described theoretically in a satisfactory manner) and determining the relevant qualitative relations, the numerical analysis reduces to the determination of the values of the parameters characterizing the process to be modelled [1]. This may be achieved by measuring certain quantities connected by a known relation with the unknown parameters, and then determining them by parametric identification of the mathematical model [2].

## 2. THE MATHEMATICAL MODEL OF THE PROCESS

To analyse theoretically the process, we assumed as a first approximation a discrete, one-dimensional nonlinear model [4], in which the influence of the type of load on the resistance to displacement inside the body of the universal trailer [5] was taken into consideration. The physical model of a system composed of a chain-slat conveyor (its driving gear being included) and the trailer is represented in Fig. 1.

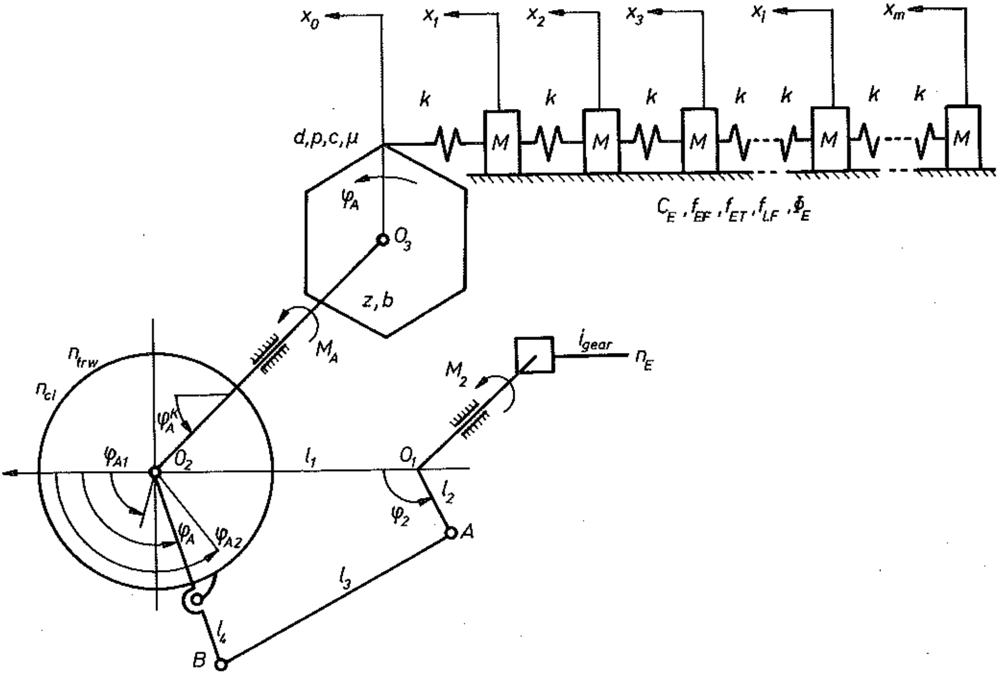

FIG. 1. Physical model of the process.

The mathematical model of the process has the form [4, 5]

$$M\ddot{\mathbf{x}} + C_E\dot{\mathbf{x}} + \mathbf{K}\mathbf{x} + \mathbf{K}^*x_0 + A = 0, \tag{2.1}$$

where $\mathbf{x} = [x_1, x_2, ..., x_m]$ is an $m$-element conveyor slat displacement matrix and $x_0$ – a displacement constituting the kinematic action exerted on the loaded conveyor, and having the form of a nonlinear function of geometrical and operation parameters of the drive gear of the conveyor

$$M = (x_E y_E z_E - x_S y_S z_S)\rho_E \ \text{[kg]},$$

$C_E$ – coefficient of viscous damping [Ns/m], $\mathbf{K}, \mathbf{K}^*$ – stiffness matrices, expressed as follows:

$$\mathbf{K}_{m\times m} = \left[\begin{array}{cccc:cccc} 2k & -k & 0 & 0 & 0 & 0 & 0 & 0 \\ -k & 2k & -k & 0 & 0 & 0 & 0 & 0 \\ 0 & -k & 2k & -k & 0 & 0 & 0 & 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & 0 & 0 & -k & 2k & -k & 0 \\ 0 & 0 & 0 & 0 & 0 & -k & 2k & -k \\ 0 & 0 & 0 & 0 & 0 & 0 & -k & k \end{array}\right], \quad \mathbf{K}^*_{1\times m} = \begin{bmatrix} k \\ 0 \\ 0 \\ 0 \\ \cdots \\ 0 \end{bmatrix},$$

$$A = (x_E - x_S) z_E y_E \rho_E g f + z_S x_S (y_E - y_S) \rho_E g f_{SF}$$
$$+ \left[(x_E - x_S) y_E^2 + x_L (y_E - y_S)^2\right] \mathrm{tg}^2(45^\circ - 0.5\Phi_E)\rho_E g f_{ET} \qquad \text{[N]}.$$

The remaining notations are assumed according to [4, 5], cf. Table 1.

The model described by the formula (2.1) is a set of $m$ (with high degree of scatter of eigenvalues), nonlinear, ordinary differential equations of the second order.

The initial conditions were determined from the relation

$$(2.2) \qquad 2x_i^0 - x_{i-1}^0 - x_{i+1}^0 = -A/k, \qquad \dot{x}_i^0 = 0, \qquad \text{for} \qquad i = 1, \ldots, m.$$

They express the stage of the process just before the beginning of the motion of the conveyor, after preliminary displacement of the load. The load acting on the $i$-th slat is in the limit state of starting the motion.

The model was solved by means of a procedure which is a modified version [4] of the DIFSUB procedure [6,7] elaborated in 1971 by E.W.Geer and constituting a good scheme for numerical integration of the initial value problem for a large set of ordinary differential equations.

For comparative description and estimation of the conveyor operation certain physical quantities are separated including the unit unloading work (the quantity of energy necessary to remove from the nominally full trailer a unit volume of the load), which is defined as

$$(2.3) \qquad L_j = \int_0^{\phi_{2j}} M2(\phi)\,d\phi \ \ [\mathrm{J/m^3}],$$

where $\phi_{2j}$-the rotation angle of the crank (of the crank-ratchet gear) necessary for unloading a unit volume of the load and $M2(\phi)$-the moment of the force acting in the drive gear of the conveyor, Fig. 1.

The relation (2.3) is a measure of power consumption during the unloading process. The quantity $L_j$ may be used as a basis for comparative estimation of the conveyor systems studied (as regards the energy consumption during the process), obviously for a model with identified parameters.

**Table 1.**

| The RT – 1/3.5 Trailer | | | | |
|---|---|---|---|---|
| $n_E$ | = | 360.0 | [r.p.m.] | engine speed of the tractor |
| $i_{gear}$ | = | 0.1682 | [-] | axle ratio |
| Crank-ratchet gear | | | | |
| $l_1$ | = | 0.374 | [m] | base length |
| $l_2$ | = | 0.075 | [m] | crank length |
| $l_3$ | = | 0.309 | [m] | connecting link |
| $l_4$ | = | 0.240 | [m] | rocker link |
| $n_{cl}$ | = | 3 | [-] | position of the control lever |
| $n_{trw}$ | = | 80 | | number of teeth of the ratchet wheel |
| The chain-slat conveyor | | | | |
| $x_S$ | = | 0.065 | [m] | dimensions of the conveyor slat |
| $y_S$ | = | 0.022 | [m] | |
| $z_S$ | = | 1.750 | [m] | |
| $b$ | = | 0.0507 | [m] | distance between the bottom of the wheel seat and its axis |
| $d$ | = | 0.011 | [m] | chain link thickness |
| $p$ | = | 0.031 | [m] | chain pitch |
| $z$ | = | 6 | | number of teeth of the chain wheel |
| $c$ | = | 0.014 | [m] | internal width of chain link |
| $k_1$ | = | $4.883 \cdot 10^6$ | [N/m] | chain stiffness |
| $n$ | = | 2 | | number of chains of the conveyor |
| $m$ | = | 10 | | number of slats in the sweeping part of the conveyor |
| The load: medium nut coal | | | | |
| $x_E$ | = | 0.310 | [m] | dimensions of an element of the load |
| $y_E$ | = | 0.500 | [m] | |
| $z_E$ | = | 1.750 | [m] | |
| $\rho_E$ | = | 900.0 | [kg/m$^3$] | mass density of the load |

## 3. THE IDENTIFICATION PROBLEM AND METHOD

The above mathematical model of the process will be adequate if it describes, also in a quantitative manner, the process of unloading of a particular material from a particular universal trailer. The model is made adequate by determining, by means of a computer, the values of the parameters of the mathematical model, use being made of the data obtained by experimental unloading of the trailer. The identification method applied is based on the minimization of the error of fitting the model to the real system (minimization of the integral-quadratic identification quality index, defined in an appropriate manner, under the existing limitations imposed on the parameters).

The parameters of the process assumed for identification are the coefficient of viscous damping $C_E$, the coefficients of friction between the load and the floor $f_{EF}$, between the load and the trailer's side $f_{ET}$ and between a slat and the floor $f_{SF}$ as well as the internal angle of friction of the load $\Phi_E$ and the coefficient of friction $\mu$ in an articulation of the chain.

Sufficiently accurate determination of the real values of those parameters by other methods is, in the case of a real system, practically impossible or very expensive.

In view of the fact that only one physical quantity (the moment $M2(t)$ in the driving gear of the crank-ratchet mechanism can be measured), identification quality index is assumed as a measure of the difference between the value of the moment M2(t) obtained by experimental means and that obtained by computer simulation of the mathematical model, $M2_M(t)$.

As a result of discretization of the time axis the identification quality index takes the form

$$E = 0.5 \sum_j \Delta t_j [M2(t_j) - M2_M(t_j)]^2 . \tag{3.1}$$

It should be observed that the index $E$ expressed by the relation (3.1) has many local minima.

Identification was performed for a six-dimensional vector of parameters, characterizing the friction phenomena occurring during the process considered, and having the form

$$\beta = [C_E, f_{EF}, f_{ET}, f_{SF}, \Phi_E, \mu] . \tag{3.2}$$

The identification procedure was that of determining the values of the $i$-th components of the vector $\beta$ of parameters of the mathematical model with the upper and lower bounds

$$\beta_{\min i} \le \beta_i \le \beta_{\max i} . \tag{3.3}$$

The limiting values of the parameters $\beta_i$ were assumed on the basis of the results of preliminary laboratory investigations ($\Phi_E$, $f_{EF}$, $f_{ET}$, $f_{SF}$), some literature data ($\mu$) and by intuition ($C_E$).

The identification of the parameters of a mathematical model consists in finding a vector $\beta^*$ such that the discrepancy between the process studied and its mathematical model measured at the output of the process is minimum within the given time interval $t \in < 0, T >$, a measure of that discrepancy being the value of the function $E$, Eq. (3.1). Thus, the identification problem has been reduced to that of determination of a minimum of the identification quality index in the space of parameters $\beta$, the limitations (3.3) being taken into consideration. This identification procedure is illustrated in Fig. 2.

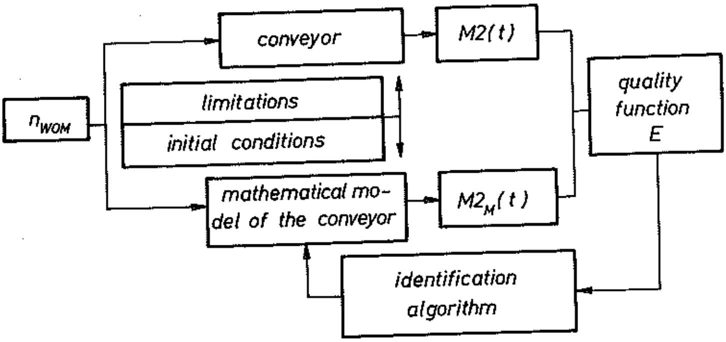

FIG. 2. Identification procedure of the model conveyor.

## 4. EXAMPLES OF IDENTIFICATION RESULTS

Identification of parameters of the mathematical model of the unloading process of a universal agricultural trailer was performed on the basis of the results of studies of the process of coal unloading from the body of an RT – 1/3.5 trailer by means of a simple chain-slat floor conveyor driven by means of a simple crank-ratchet driving gear. Experimental data concerning the variation of the moment $M2(t)$ were recorded along the measurement set composed of an inductance moment meter MI-50 (made by PIMR – Poznań), a strain-gauge amplifier TT6C (ZELMET – Warsaw) and a loop oscillograph K-121 (USSR).

The data assumed for identification are presented in Table 1. The COMPLEX procedure [3] was used for minimization of the function $E$, thus enabling identification of the multi-dimensional vector of parameters and ensuring the global minimum being found for an ill-conditioned problem of conditional minimization of the identification quality index.

As a result of computation the values of the parameters identified were found to be as follows:

$$C_E = 13793.51 \qquad [\mathrm{Ns/m}]$$
$$f_{EF} = 0.21,$$
$$f_{ET} = 0.35,$$
$$f_{SF} = 0.26,$$
$$\Phi_E = 34.46 \qquad [\mathrm{stop}],$$
$$\mu = 0.62.$$

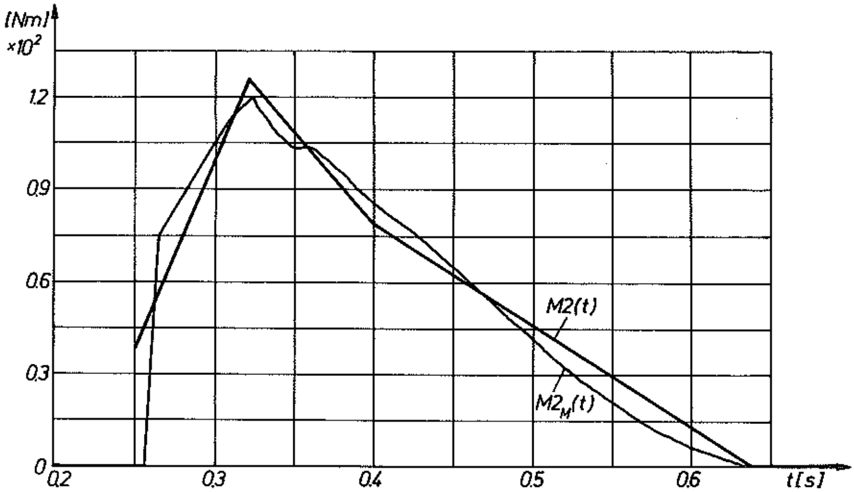

FIG. 3. Variation of the moments $M2_M(t)$ and $M2(t)$ during a single working cycle of the conveyor.

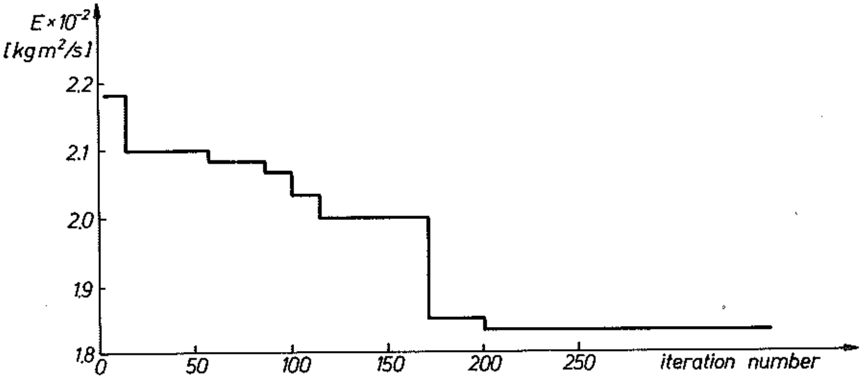

FIG. 4. Variation of the index $E$ in the course of the computation process.

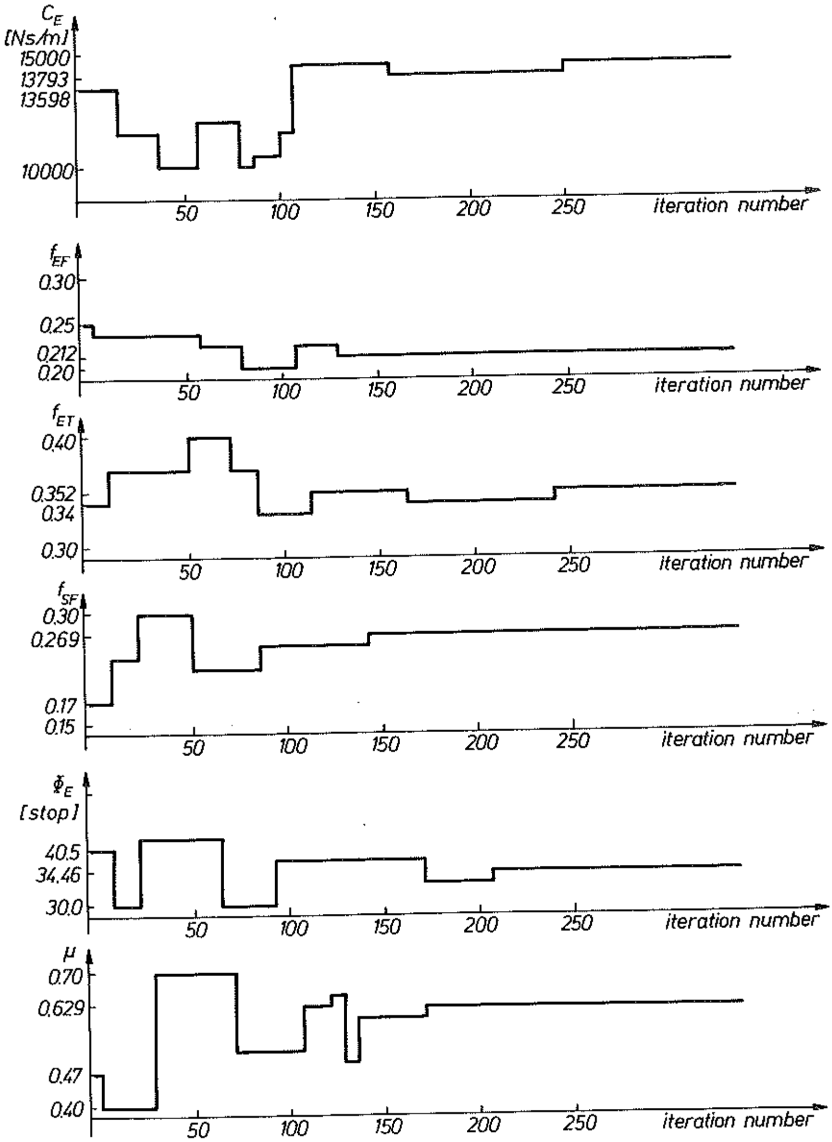

FIG. 5. Variation of vector $\beta$ components during the analysis.

Figure 3 illustrates the variation of the moment $M2_M(t)$ obtained by simulation of the model with identified parameters against the background of the moment $M2(t)$ averaged from 18 working cycles of the conveyor in the real system. The variation of the identification quality index $E$ in the course of the process is represented in Fig. 4, and the identified parameters $\beta$ — in Fig. 5.

Variation of the components of the vector parameters $\beta$ and the identification quality index $E$ during the identification process confirm the convergence of the identification process by the COMPLEX method.

## 5. FINAL REMARKS

The identification method presented here concerns a certain class of engineering processes, namely that of unloading, by means of a chain-slat floor conveyor, a universal agricultural trailer; the method may be used for studying the operation of other systems of the same class. The identification method of the parameters of the mathematical model used here and based on a single physical quantity enables us to determine the values of several (six) different parameters of the mathematical model. The results of identification quoted here are valid for a conveyor of the particular type considered (and for a given material of the load). In the basis of a simulation study [4] of an RT-1/3.5 trailer, two ways for improving the efficiency of the process have been indicated. The importance of the initial phase of work of the pawl and ratchet mechanism for the dynamic loads of the system is emphasized.

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## STRESZCZENIE

### IDENTYFIKACJA PARAMETRYCZNA MODELU WYŁADUNKU PRZYCZEPY UNIWERSALNEJ

Przedstawiono metodykę identyfikacji wartości parametrów pewnego dyskretnego, jednowymiarowego, nieliniowego modelu matematycznego procesu wyładunku materiału ze skrzyni ładunkowej rolniczej przyczepy uniwersalnej. Problem identyfikacji rozwiązano jako zadanie numerycznej minimalizacji warunkowej przy zastosowaniu algorytmu COMPLEX. Przedstawiono wyniki obliczeń numerycznych na przykładzie wyładunku węgla kamiennego z przyczepy typu RT/3,5.

## РЕЗЮМЕ

### ПАРАМЕТРИЧЕСКАЯ ИДЕНТИФИКАЦИЯ МОДЕЛИ ПРОЦЕССА РАЗГРУЗКИ УНИВЕРСАЛЬНОГО ПРИЦЕПА

Представлена методика идентификации значений параметров некоторой дискретной одномерной нелинейной математической модели процесса разгрузки кузова универсального сельскохозяйственного прицепа. Задача идентификации решена как задача численной минимизации с ограничениями с использованием алгоритма COMPLEX. Представлены результаты численных расчетов на примере разгрузки каменного угля из прицепа модели RT-1/3,5.

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*Received March 28, 1991.*