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# ON EXPERIMENTAL IDENTIFICATION OF SELECTED DRY FRICTION MODEL

*SUMMARY*

*The paper concerns with an identification problem of selected dry friction model on a basis of results of vibration experimental investigations of the given mechanical system. The system structure implicates a shape of its dynamics motion equations from these one can assign the friction model (function), taking under consideration the values assigned in measurements as following: displacements, velocities and accelerations meeting specified exploitation inputs (loading, velocities) of the defined friction pairs. The model can be used in mechanical systems for design and exploitation.*

**Keywords:** *dry friction model, vibrations induced by friction*

*O DOŚWIADCZALNEJ IDENTYFIKACJI PEWNEGO MODELU TARCIA SUCHEGO*

*Praca dotyczy zagadnienia identyfikacji pewnego modelu tarcia suchego przy wykorzystaniu wyników eksperymentalnych badań drgań określonego układu mechanicznego. Struktura układu implikuje postać jego dynamicznych równań ruchu, z których przy wyznaczonych w pomiarach przemieszczeniach, prędkościach i przyspieszeniach, odpowiadających zadanym wymuszeniom eksploatacyjnym (obciążeniom, prędkościom) określonych par ciernych, można wyznaczyć model (funkcję) tarcia. Model ten można wykorzystać w badaniach symulacyjnych drgań wzbudzanych tarciem suchym w układach mechanicznych, na etapie ich projektowania i eksploatacji.*

**Słowa kluczowe:** *model tarcia suchego, drgania wzbudzane tarciem*

## 1. INTRODUCTION

Friction has an important influence on operation quality of many mechanical systems, in these on their durability and reliability (Michalczyk 1995). It also exists in many technical processes [eg. in machining and rolling] and generally it is used for vibration damping with friction dampers and also for induction of sounds, e.g. in stringed instruments.

In some conditions friction can be a source of vibrations and we say it is case of self-exciting phenomenon caused by friction. Many carried out investigations show that friction can induce friction and also through vibration one can influence on friction; e.g. in robot manipulators vibrations are induced for stabilization of position. These two aspects of friction and vibration correlation are still important problem and subject of interest of many researchers concerning with friction, dynamics and exploitation of mechanical systems (Awrejcewicz *et al*. 2005; Bogacz and Ryszek 1996, 2001; Engel and Kowal 1995; Bogusz *et al*. 1976; Furmanik 2006, Giergiel *et al*. 1967; Grudziński *et al*. 1993; Lenkiewicz 1967; Popp and Stelter 1990; Ryczek 2001). In the field of environmental protection of human being the knowledge on vibrations induced by friction is essential (Engel and Kowal 1995; Michalczyk 1995; Nizioł 1998).

An increase of utility requirements concerning with machines and equipment is connected with necessity of solution of many problems, in this number also with dynamics contact problems of dry friction. The proper analysis of behaving of mechanical systems with friction requires an application of satisfactory friction models (it means mathematical dependences on parameters which explicitly characterize the friction process in defined conditions of its realization), pointed out on experimental way. A class of friction model is connected with the structure of mechanical system, its exploitation inputs and friction pair properties. The friction model is so better as faithfully describes the real friction process.

New investigation tools like advanced computer technologies, measurement systems, systems of data acquisition and processing enable construction of such models.

The paper presents the problem of selected dry friction model identification on the basis of experimental investigation results of vibrations induced by dry friction, assumed to the mechanical system.

## 2. IDENTIFICATION OF FRICTION MODEL

The basic problems of dynamics are two theoretical problems. The first one concerns with definition of forces operating onto system, when the motion description is known, the second one concerns with finding of kinetic values characterizing a system motion at known loading and properties of this system. These problems are considered as reciprocal, associate through differential equations of system motion. The first problem is the identification of friction model (function),

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using the equations of investigated motion of physical system and results of measurements in real time of its displacements, velocities and accelerations. The second problem is the simulation of system motion at assumed or earlier identified friction model corresponding with materially defined friction pair and its exploitation inputs (loadings and velocities).

The friction model of the investigated friction pair one can be verified on way of simulation investigation comparison results with results of experimental investigations. The computer aided method of identification of friction model enable numerical testing of this model using the computer simulation methods. The results of experimental investigations can be the basis to verification of theoretical analysis and simulation testing results.

## 3. EXPERIMENTAL INVESTIGATIONS OF DRY FRICTION SYSTEM

The system which is analyzed in the paper is a kind of physical pendulum shown in scheme in Figure 1a, put in motion due to a frictional contact with inner side surface of steel or cast iron drum, rotating with constant velocity around vertical axis covering a pendulum axis.

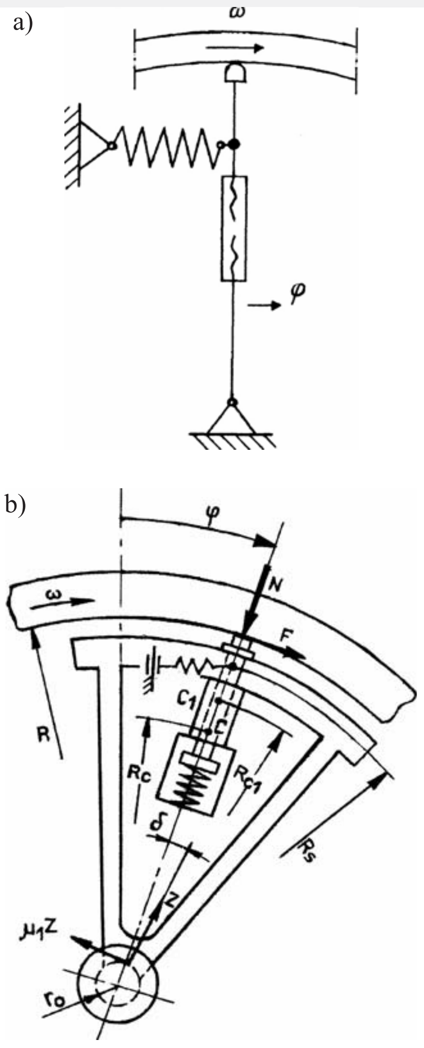



**Fig. 1.** Scheme (a) and construction (b) of testing system

The friction contact is realized through friction elements fixed onto pendulum in construction providing a control of thrust force between frictional elements. The return pendulum motion insures a steel spring joined at one end with vibrating pendulum and at the second end with a frame of stand.

Using notations given in Figure 1b and assumption of ideal outline of friction surface the system dynamic equilibrium equations have the following shape:

$$-N + Z\cos\delta + Z\mu_1 \sin\delta \,\mathrm{sgn}\,\dot{\varphi} - S\sin\varphi = -mR_c\dot{\varphi}^2$$

$$N\mu\,\mathrm{sgn}\,v_{wz} + Z(\sin\delta - \mu_1\cos\delta\,\mathrm{sgn}\,\dot{\varphi}) - S\cos\varphi = mR_c\ddot{\varphi} \qquad (1)$$

$$I_0\ddot{\varphi} = -SR_s\cos\varphi + N\mu R\,\mathrm{sgn}\,v_{wz} - Z\mu_1 r_0\,\mathrm{sgn}\,\dot{\varphi}$$

where:

- $F = \mu N$ – friction force of frictional element against drum,
- $N$ – current thrust of frictional element towards side surface of drum,
- $S = kR_s\sin\varphi$ – force in spring,
- $R_s$ – radius of elastic link fixing,
- $R_c$ – radius to qualify of mass centre (with frictional element),
- $k$ – coefficient of elasticity constraint,
- $m$ – pendulum mass (with frictional element),
- $Z$ – force of thrust into bearing,
- $\delta$ – thrust force Z deviation angle,
- $v_{wz} = (\omega - \dot{\varphi})R$ – relative slide velocity,
- $\mu(t)$ – coefficient (function) of friction between frictional element and drum,
- $\mu_1$ – reduced coefficient of friction into bearing,
- $r_0$ – bearing radius,
- $\varphi$ – angle of deflection of pendulum from equilibrium position,
- $I_0$ – pendulum inertia mass moment (with frictional element) towards drum rotation.

Solving the system equations (1) we have obtained an expression which has been used for identification of the friction model:

$$\mu(t) = \\ = \frac{1}{N\,\mathrm{sgn}\,v_{wz}}\left[I_0\frac{\ddot{\varphi}}{R} + k\frac{R_s^2}{R}\sin\varphi\cos\varphi + \mu_1 Z\frac{r_0}{R}\,\mathrm{sgn}\,\dot{\varphi}\right] \qquad (2)$$

where quantities $\varphi$, $\dot{\varphi}$, $\ddot{\varphi}$ were assigned from measurement way.

Scheme of measurement system of investigation stand was shown in Figure 2.

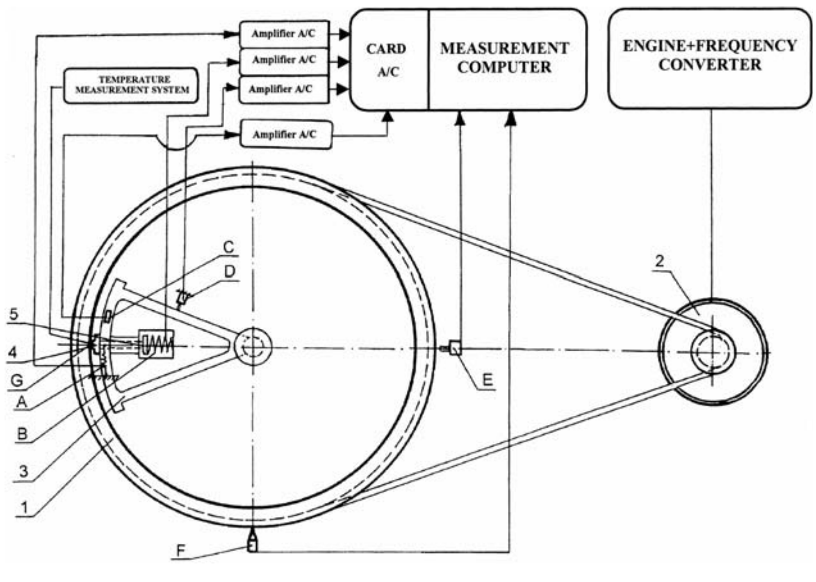



**Fig. 2.** Scheme of testing stand measurement system
See explanation in text

A drum 1 drives engine 2 (Fig. 2) of regulated supply voltage, what ensures the gaining of steeples change of its motion velocity in a wide range. The arch segment 3 joins a flat elastic element "A" (with stuck on strain gauges) with a frame of stand. It enables measurements of circuit forces and displacements. The control of thrust force of frictional element 4 towards drum ensures a screw element 5 and flat spring "B", on which there are strain gauges enables this force measurement. The construction of stand is such that a co-operation of frictional elements made of different materials is possible, both with side surface of drum (in the aim of drum break operation representation) as with its bottom (case of disk break operation).

The measurement of acceleration of segment motion enables a piezoelectric accelerometer "C" fixed against an arch segment and the measurement of circuit velocity an induction gauge of velocity "D". The rotation velocity of drum was measured using an opto-electronic gauge "E", and the number of drum rotations by the gauge "F". The gauge for temperature measurement ( thermoelement ) "G" is joined with frictional element.

The measurement signals were recorded by measurement computer after sufficient amplification.

The expression (2) defining the friction function has been applied into identification problem, where the quantities $\varphi$, $\dot{\varphi}$, $\ddot{\varphi}$ have been assigned on measurement way in real time. The scheme of procedure for friction model identification, constructed on the basis of VisSim & Analyze package, ver.2.0.b, in the case of thrust force control of PWM signal character (like in real system character of loading) has been presented in Figure 3.

The essential problem of experimental investigations was a setting of variability range and control quantity values (control parameters, thrusts and velocities) for assumed friction pair matchings (Fig. 4).

The range of variability of these parameters resulted from a construction of testing stand and met specified those into real systems, and their values were assigned using a determined, selective and many factor schedule of investigation, uniform-rotational (PS/DS – P:λ) [7].

The nominal values of control quantities of investigations were following:

– thrust forces of frictional element towards drum

$$P \in \{P_1;\ P_2;\ P_3;\ P_4;\ P_5\};$$

– drum circuit velocity on friction surface

$$v_0 \in \{v_1;\ v_2;\ v_3;\ v_4;\ v_5;\ v_6;\ v_7;\ v_8;\ v_9\}.$$

The independent variables of investigations were:

– materials of friction pair;
– control quantities: frictional element thrust force towards drum and drum circuit velocity;
– dynamic system parameters: mass, inertia moment, rigidity.

The selection of friction model was determined by the need of getting of possibly faithful representation of vibrations occurring in real system, as well as getting possibly the best describing statistics for measurement results. Among many analyzed models it was accepted the following model of many parameter function:

$$\mu(v_{wz}) = A \cdot [1 - \exp(-B \cdot v_{wz})] \cdot \exp(-C \cdot v_{wz}) + D \cdot v_{wz} + E \quad (3)$$

where:

$\mu(v_{wz})$ – friction model (coefficient),
$P$ – initial thrust force of frictional element towards drum [N],
$v_{wz}$ – slide velocity of frictional element [m/s],
$A$, $B$, $C$, $D$, $E$ – deflection coefficients assigned by method of least squares (using corresponding statistical programs) according to $P$ i $v_0$.

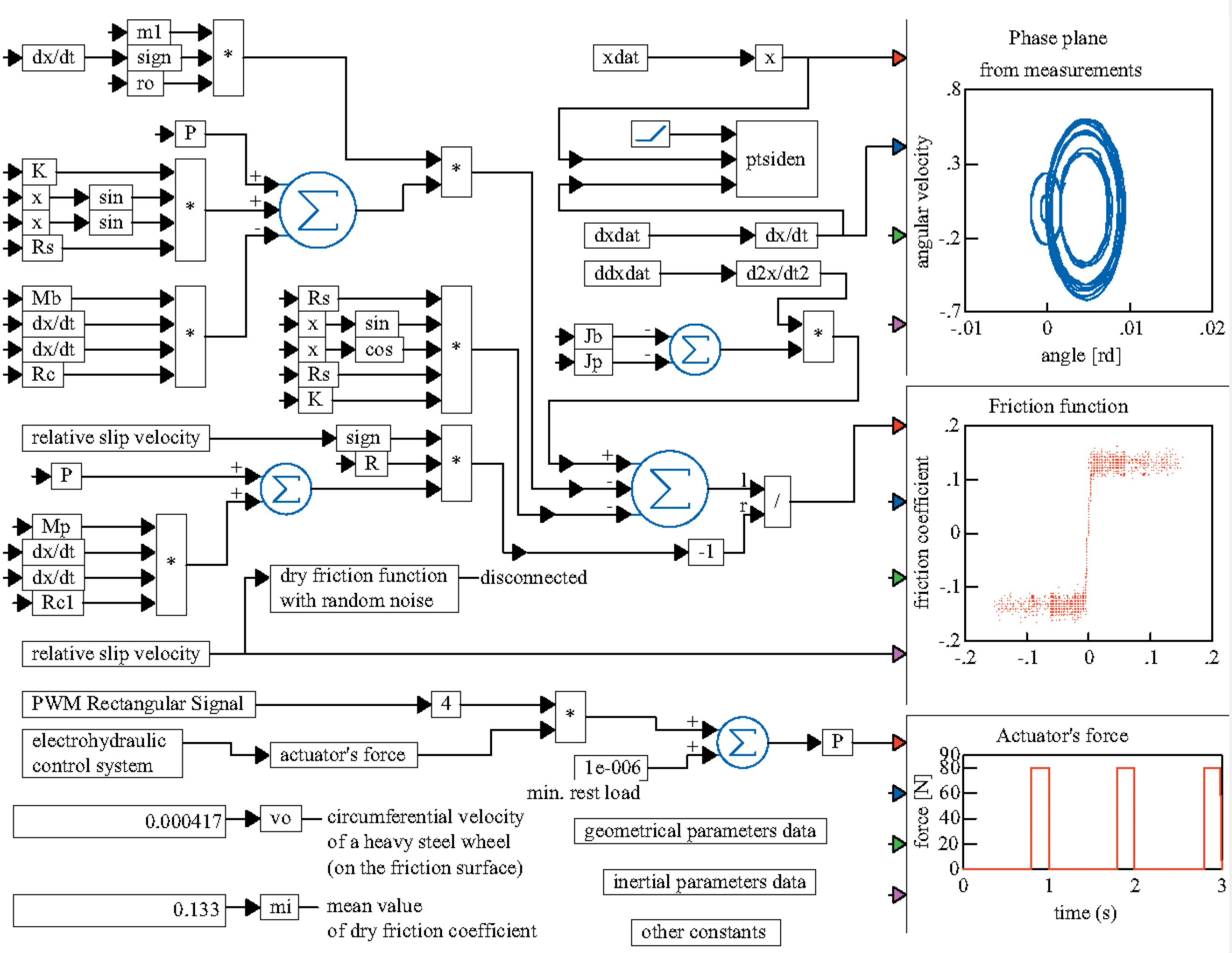



**Fig. 3.** Scheme of procedure for identification of investigated friction function of mechanical system

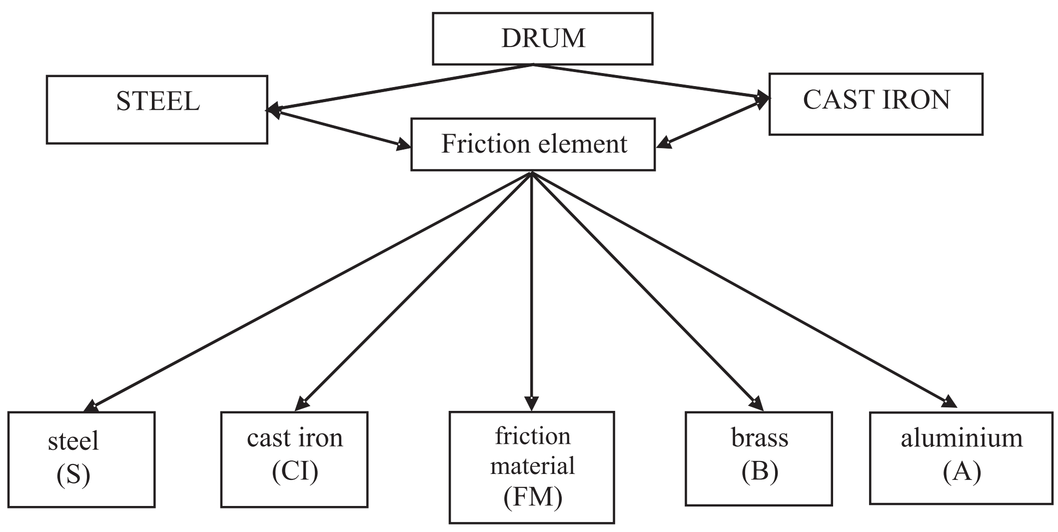
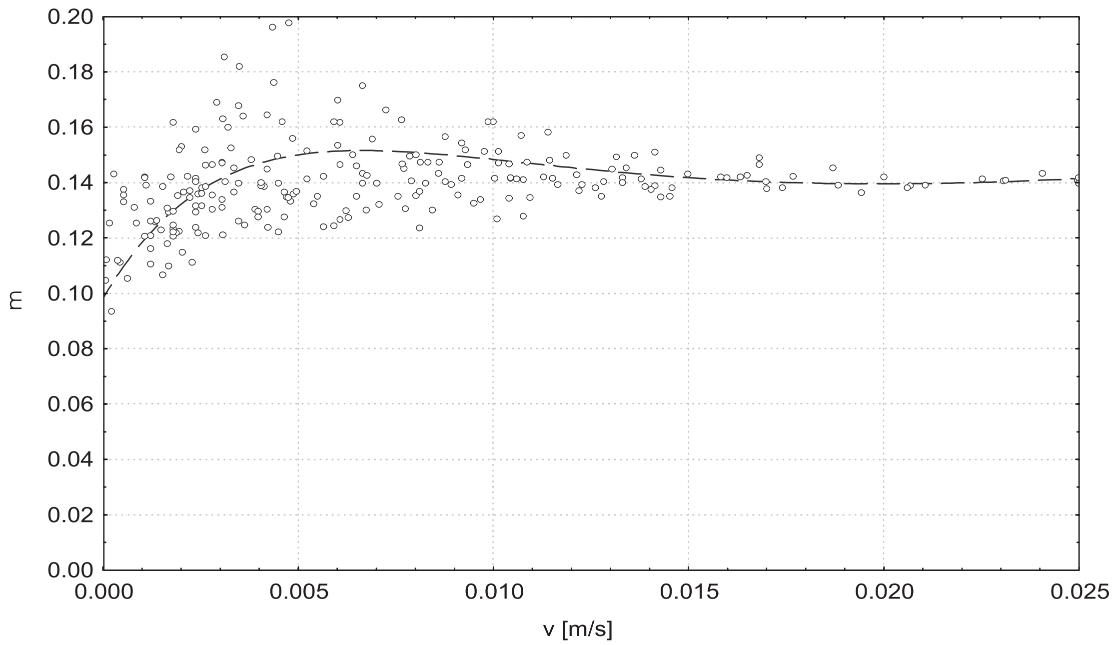



**Fig. 4.** Set of materials matchings of investigated friction pairs

The experimental investigations enabled assignment of parameter values of the friction model corresponding with investigated matchings of friction pairs and values of control quantities. In Figure 5 friction characteristics corresponding with assumed friction model for friction pair: drum – frictional element: steel – steel has been presented.




$$\mu = 0.3185 \cdot [1 - \exp(-71.06 \cdot v_{wz})] \cdot \exp(-152.63 \cdot v_{wz}) + 1.5 \cdot v_{wz} + 0.09981645$$

**Fig. 5.** Friction characteristics where: $P = 28.539$ N, $v_0 = 0{,}0066$ m/s ($R = 0.7837$) for friction pair: steel – steel

## 4. REMARKS AND FINAL CONCLUSIONS

The friction model assigned on experimental way of vibrations induced by dry friction in mechanical system in essential way depends on structure of this system, exploitation inputs and kind of friction pair materials. The structure implicates the shape of dynamic system motion equations, from which one can assign the friction model (function), taking under consideration the given measurements as: displacements, velocities and accelerations corresponding with assigned exploitation inputs (loadings, velocities). The selected friction model ought to insure possibly well the representation of observed vibrations into real system, as well as the possibly best description statistics of measurements. Carried out simulation tests show the great dependence of shape of investigated mechanical system motion on assumed friction model (Furmanik 2006).

The results of carried out experimental investigations and simulations one (Furmanik 2006) allow to present the following conclusions:

1) The behaviour of mechanical system with dry friction depends on assumed friction model in essential way, because its parameters depend on kind of friction pair materials and values of control parameters (thrust force, velocities).
2) In the range of small velocities for many friction matchings one obtains the friction model with a characteristic so called "hump".
3) For assumed friction model one observes vibrations of a type "stick-slip" according to the kind of friction pair materials and control parameter values, quasi-periodic, so called "smooth slide" and chaotic vibrations.
4) The friction models assigned on experimental way can be the basis of motion analysis of investigated mechanical system, both on the stage of designing and exploitation.

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