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A CONTRIBUTION TO APPLICATION OF THE MATHEMATIC MODELING METHOD FOR PROGNOSIS OF THE FRICTION COEFFICIENT BEHAVIOUR

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***Abstract**.*
The friction coefficient depends of a number of the many factors and can vary within wide boundaries. When the characteristics of material and geometric characteristics of the elements of the friction pair are well-known in advance, the pressure, velocity and temperature have the strongest influence on the friction coefficient.
In the other hand, in tribomechanics systems it is desirable to know the law of the changes of the friction coefficient with these parameters changes. However, considering the complexity of the friction process, establishment of an adequate function is a difficult problem.
This paper presents one possibility of using the mathematic modeling method for prognosis of the friction coefficient behaviour in the case when the friction pair is made of composite and cast iron.

Key words: *friction coefficient, mathematic modeling*

1. INTRODUCTION

For determination of friction characteristics of materials for breaking insertions, research of their characteristics, in all regimes and in all working conditions is needed. Those researches are developed in either exploiting conditions, either, more often, in laboratory. But, because of complex relationships between parameters, involved in tribological characteristics of friction pair, in this case, all researches are long termed and expensive. From that point of view, use of mathematical modeling method enables more efficient experiments. In order to predict behaviour of friction coefficient of railway disk brakes, made of composite materials, this method. is used in FIAZ factory, Prokuplje, Serbia & Montenegro.

2. SELECTION OF MATHEMATICAL MODEL

Process of friction and wear of contact surfaces of working elements of brakes is very complex. Parameters that involve in that process, are various and related between themselves. Because of that, for appropriate functional relationship's choice, the most important is- defining level of influence of some factors. For that purpose, involving factors are divided in two great groups. First group of factors includes factors associated with working conditions, the way of use of brakes. There are included pressure (p), velocity (v) and temperature (θ). Second group of factors includes factors which are accoiated with influence of construction (D), characteristics of breaking insertion materials (MO) and properties of metal element (ME). Functional relationship between all this factors can be shown in shape like in [1]

$$\mu = (p, v , \theta , D , MO , ME) \qquad (1)$$

Second group factors might be interpreted with qualifier (C_μ), which is conditionally reminded as constant for specific breaking type. Expression (1) now becomes

$$\mu = (p, v , \theta , C_\mu) \qquad (2)$$

Due literature data [1/5], basic shape of analytical expression, which can be used for describing changes of friction coefficient for large number of breaking cycles during research on inertial testing table, is

$$\mu = K\, p^{\alpha}\, v^{\beta}\, \theta^{\gamma} \qquad (3)$$

Where p, v, θ - are, respectively, pressure, velocity and temperature, while: α, β, γ and K – are coefficients.

Coefficients α, β, γ and K relate to type and dimensions of brakes, material of insertions and discs. They are experimentally found and researches like this are done on testing table PSK-30 in FIAZ, Prokuplje. On the basis of experiments and literature data, [1-5], as most proper shape of mathematical model for examined insertions of disk brakes for railway vehicles, expression is

$$\mu = 0.806\ p^{-0.0125}\ v^{-0.0673}\ \theta^{-0.176} \qquad (4)$$

Expression (4) is successfully tested for examining of behaving friction coefficient in cases when the use of testing table was impossible.

3. BASIC EXPERIMENT DATA AND PRESENTATION OF EXPERIMENT'S RESULTS

Insertions for railway disk brakes are tested on testing table PSK-30 in FIAZ, Prokuplje, by Program 2 and Program 3, which are defined by standard UIC 541-3. Program 2 involves testing of efficiency and durability period while Program 3 involves only testing of efficiency. Due to technical limitations experiment is realized with velocities 20 to 140 kilometers per hour. All experiments are done with disks made of cast iron, with diameter of 890 mm and for every new testing program, new set of breaking insertion is used.

Table 1. Structural composition of material

Component (%)	Material				
	1	**2**	**3**	**4**	**5**
Fastner	15	15	15	14	15
Coctail fibers	32	31	21	32	24
Fullers	43	45	54	45	50
Friction modificators	10	9	10	8	11

Braking insertions were made of five different composites. Their structural composition is shown in Table 1. Geometry and size of insertions is defined with standard UIC 541-3. For simulation of load on wheel, with mass of M=4,5 t (Program 3), moment of inertia used in experiment is 1530 kgm^2. Friction coefficient is experimentally measured for value of velocity, pressure and temperature, determined with standard UIC 541-3. Friction coefficient is estimated by expression (4), also.

Table 2. θ = 100^0

v (km/h)	p (bar)	θ (^{0}C)	μ_M (model)	μ_E (eksper.)
20	1	100	0.372	0.365
60	1	100	0.377	0.380
120	1	100	0.380	0.381
20	2	100	0.355	0.335
60	2	100	0.360	0.363
120	2	100	0.363	0.363
20	3	100	0.345	0.344
60	3	100	0.350	0.352
120	3	100	0.353	0.354
20	4	100	0.339	0.342
60	4	100	0.343	0.345
120	4	100	0.346	0.342
20	5	100	0.334	0.340
60	5	100	0.338	0.341
120	5	100	0.341	0.343

Arithmetical average: 0,353 0,352

Table 3. $\theta = 150^0$

v (km/h)	p (bar)	θ (^{0}C)	μ_M (model)	μ_E (eksper.)
20	1	150	0.346	0.351
60	1	150	0.351	0.343
120	1	150	0.354	0.354
20	2	150	0.331	0.332
60	2	150	0.335	0.332
120	2	150	0.338	0.343
20	3	150	0.322	0.326
60	3	150	0.326	0.334
120	3	150	0.329	0.332
20	4	150	0.315	0.298
60	4	150	0.320	0.331
120	4	150	0.322	0.336
20	5	150	0.311	0.325
60	5	150	0.315	0.336
120	5	150	0.318	0.302
Arithmetical average:			*0,328*	*0,331*

In Tables 2. to 6, are shown comparative data for friction coefficient estimated by mathematically model (μ_M) and experimentally (μ_E) only for breaking insertions worked from material number 5 from Table 1.

Table 4. $\theta = 200^0$

v (km/h)	p (bar)	θ (^{0}C)	μ_M (model)	μ_E (eksper.)
20	1	200	0.329	0.331
60	1	200	0.334	0.351
120	1	200	0.337	0.337
20	2	200	0.314	0.326
60	2	200	0.318	0.302
120	2	200	0.321	0.301
20	3	200	0.306	0.302
60	3	200	0.310	0.321
120	3	200	0.313	0.323
20	4	200	0.299	0.300
60	4	200	0.304	0.331
120	4	200	0.306	0.298
20	5	200	0.295	0.286
60	5	200	0.299	0.301
120	5	200	0.302	0.326
Arithmetical average:			*0,312*	*0,315*

Table 2., shows data for, so called, “cold breaks”, when its temperature is not above 100^0 C and in Tables 3. and 4. for working temperatures from 150^0 and 200^0 C.

Comparing the results, it is seen that friction coefficient received experimentally and calculated mathematically by expression (4) have average deviation is about 4%. Individually deviation is up to 8.1%. Average values of friction coefficients are similar, also.

In Table 5, data is shown for case when working temperature of breaks is high. As can be seen, deviation of value of friction coefficients received experimentally and mathematically, in average, varies between ± 4 %. Individually deviations are greater and they are up to 9%. Also, difference of averages is greater then with lover temperatures, but it is in approved limitations.

Table 5. $\theta = 250^0$

v (km/h)	p (bar)	θ (^{0}C)	μ_M model	μ_E eksper.
20	1	250	0.316	0.332
60	1	250	0.321	0.342
120	1	250	0.324	0.335
20	2	250	0.302	0.324
60	2	250	0.306	0.332
120	2	250	0.309	0.322
20	3	250	0.294	0.323
60	3	250	0.298	0.318
120	3	250	0.301	0.321
20	4	250	0.288	0.309
60	4	250	0.292	0.295
120	4	250	0.295	0.295
20	5	250	0.284	0.286
60	5	250	0.288	0.291
120	5	250	0.290	0.296
Arithmetical median:			*0,305*	*0,313*

In Table 6, data is shown for friction coefficient when the velocities are high and temperature refers to cold breaks. Experimental values are researched in Laboratory Refer, Romania. In this Laboratory the measured value of friction coefficient for all other values p, v, θ, was shown satisfactory agreement with calculated.

Table 6. $\theta = 100^0$

v (km/h)	p (bar)	θ (^{0}C)	μ_M model	μ_E eksper.
140	1	100	0.381	0.401
140	2	100	0.364	0.375
140	3	100	0.354	0.355
140	4	100	0.347	0.335
140	5	100	0.342	0.308
160	1	100	0.382	0.406
160	2	100	0.364	0.373
160	3	100	0.354	0.351
160	4	100	0.348	0.341
160	5	100	0.342	0.332
180	1	100	0.382	0.391
180	2	100	0.365	0.382
180	3	100	0.355	0.376
180	4	100	0.348	0.341
180	5	100	0.343	0.332
200	1	100	0.383	0.386
200	2	100	0.365	0.361
200	3	100	0.355	0.342
200	4	100	0.349	0.336
200	5	100	0.343	0.346
Arithmetical average			*0,358*	*0,358*

By this research, mathematically modeled values of friction coefficients, estimated by expression (4), are checked. As it is shown, in this case, also, there is good coincidence with results received by experiment and calculated by mathematical model.

Values of friction coefficients received experimentally and by mathematical model, in average, vary less then ±1 %. Individual deviations are up to 10 % but difference of averages is minor.

4. CONCLUSION VIEWS

On the base of results, can be conclused:

- Differences between calculated and experimental values of friction coefficients are very little,
- For research of friction coefficients of materials for breaking insertions of railways vehicle, mathematical modeling method can be used successfully,
- Using of mathematical modeling method makes high material and economical savings.

5. REFERENCES

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