Vol. 36, No. 1 (2014) 9-16

Tribology in Industry

www.tribology.fink.rs

RESEARCH

Tribological Aspect of Rubber Based Parts used in Engineering

D. Stamenković [a], M. Nikolić [a], M. Milošević [a], M. Banić [a], A. Miltenović [a], M. Mijajlović [a]

[a] *University of Niš, Faculty of Mechanical Engineering in Niš, Serbia.*

Keywords:

Coefficient of static friction
Rubber
Tribology
Slip resistance
Standards

Corresponding author:

D. Stamenković
University of Niš,
Faculty of Mechanical Engineering, Niš
Serbia
E-mail: dusans@masfak.ni.ac.rs

A B S T R A C T

In most of the cases, the friction is considered as a negative side-effect concerning energy loss following every process of the power transmission. However, the friction has significant positive side effects, because it is an indispensable prerequisite for the movement of people, machines, transportation means and others. Efficiency of these movements mostly depends on the friction between rubber and different materials such as metals, concrete, earth, wood, plastic, etc. Certain standards relating to measurement and determination of the friction characteristics of rubber were established. However considering that tribology of the rubber is very complex problem, numerous studies around the world are conducted. This paper gives an overview of some of the existing standards and conducted researches in this area. The paper also provides an overview of theoretical and experimental studies of friction the rubber and the other materials, which are done at Faculty of Mechanical Engineering in Niš.

1. INTRODUCTION

Movement can be realized only and merely by the friction, but during a motion, friction permanently causes different kinds of losses (energy dissipation, mass loss, movement loss). Therefore, friction is the process where positive and negative effects manifest both. In a certain situation, a large friction force is required, but in other situation small friction force is required.

Because of that, understanding the tribological interactions between the shoe and the floor materials is important in order to enhance shoe and floor design and to prevent slip and fall accidents during walking.

Since the coefficient of friction measurements were commonly adopted to evaluate slip potentials, it has been found that there were controversies in the interpretation of measurement results. The study [1] was principally focused on broadening the knowledge base and developing new ideas on which improvements in the validity and reliability of slip resistance measurements might be made. To achieve this goal, crucial problems on the current concept of slip resistance measurement were extensively analysed by a tribological point of view where principle of understanding the shoe-floor friction and wear phenomena could be made. Based on this approach, new theoretical models were suggested in paper [1].

This study discussed the limitations of present concept on slip resistance measurements and analysed the seriousness of misinterpretations on slip resistance properties that were mainly caused by over-simplified conceptions on friction phenomena between the shoe heels and floor surfaces. Based on those critical analyses, a new paradigm on friction and wear phenomena between the shoes and floors was proposed for the future researches on the slip resistance measurements.

On the basis of totality of the experimental and the simulation results as well as concepts some recommendations for dealing with the tribology of polymer-based composites – in instruction as well as industrial and research setting – are made in the paper [2].

Advantages and disadvantages of traditional and modern approaches of surface analysis based on concepts of roughness and texture are discussed in the paper [3]. Authors considered that traditional concept of rough surface based mainly on profile parameters is not fully satisfied modern trends in tribology. This paper presents a review of the problems of rough surfaces analysis in their evolution from statistical height and step parameters of profiles to dimensionless and scale invariant representation of surface texture. They concluded that texture analysis can be efficiently applied for solving practical tribological problems in micro/nanoscale.

Paper [4] presents a study on the surface quality pointing out the influence of relative sliding on the topography parameters. A comparative study of the surface topography, obtained by changing a single parameter during the tests, may reveal at least a qualitative influence of this parameter that could be useful for practicians.

The authors in paper [5] investigated the boundary friction model, that are built up by the surface topography. The model contained the effect of boundary film, adhesion, plough and lubrication. Based on the model, a coefficient for weakening plough for the lubrication was proposed. The modified model could fit for the working condition of wet friction elements.

In the paper [6] authors indicate that static friction is necessary for vehicle starting and running and show comparative information of static friction experiment of prismatic steel samples slip and tribology studies of the wheel-rail contact.

The new friction coefficient calculation procedure based on the Molecular-mechanical theory of friction is proposed in the paper [7]. This procedure considers roughness parameters and hardness of contact surfaces, as well as the relationship between the deformation component of the static friction coefficient and the total static friction coefficient determined experimentally for specific tribological conditions. Studied tribological conditions in the research are related to the press fit joints of railway vehicles drive unit components. The proposed model considers experimental research of tribomechanical pairs at which plastic deformations exist in the real area of contact.

A review of standards and methods of slip resistance measuring provided by flooring and footwear suppliers in United Kingdom is presented in paper [8]. It can be seen that a lot of suppliers didn't specify date about the slip resistance of their products.

The lack of international standards for the slip resistance of ceramic tiles is stated in the paper [9]. The paper considers recent and current potential developments in the international standardization of slip resistance. It identifies some limitations of wet barefoot ramp test, and suggests that changes should be made.

The paper [10] researches the friction between rubber and metal which can significantly influences damping characteristics of the rubber-metal springs. In the framework of the experimental research that has being conducted the coefficient of the static friction between the rubber and metal has been established in different contact conditions. Moreover, compressions of rubber-metal springs are also performed and force-deflection diagrams are recorded. In this way, the mutual influence of the static friction between the rubber and the metal pad and the accumulated/absorbed energy within a rubber-metal spring is analyzed.

Tribological approach of the contact footwear-floor is the subject of research that has started at Faculty of Mechanical Engineering in Niš. Experimental research of static friction of footwear rubber samples and different types of floor materials is presented in this paper.

2. STATIC FRICTION

In order to achieve vehicle wheel turning on the road, it is necessary to have the drive torque as well as a force of resistance in the wheel-road contact. Similarly, in order to make walking on the floor possible, a drive force delivered by the legs and a force of resistance in the footwear-floor contact are needed. This resistance is the static force of sliding friction. So, wheel rolling is achieved through the static friction force of sliding. Likewise, pedestrian can walk with the help of static friction force.

Friction represents a resisting force that opposes relative motion of bodies' surfaces that are in contact. According to the state of moving, i. e. to the resultant tangential force that induces moving there are two types of friction. The static friction or the stationary state friction that exists when the resultant tangential force is lower than the summation of all resistances that oppose moving and the kinetic friction or the moving state friction when the force that induces moving is greater than the summation of resistant forces

The diagram (F_s) in Fig. 1 shows that the force increases from the point O to the point A, where the maximal value of the force is achieved. That is the static friction force (F_s). The static friction force represents a maximal tangential resistant force that acts during so called boundary relative displacement. Boundary displacement (presliding movement) can be defined as a micro moving of frictional surfaces that goes before visible or macro moving of surfaces in mutual contact (the part OA of the graphic in Fig. 1). Futhermore, presliding movement represents a limit up to which the static friction lows between frictional surfaces are valid. After this limit the kinetic friction lows are in action. Therefore, the presliding movement is a period of relative movement characterized by an extensive increase of the reactive force and a small increase of movement. Press fit joints, screw and rivet connections, all types of friction transmitters (variators, belt transmitters, couplers), parking brakes etc. work in the mode of presliding movement.

It can be seen that the force retains the value of the static friction force (F_s) for a short time period and then decreases to the value of the kinetic friction force (F_k). This process is followed by an intensive increase of movement.

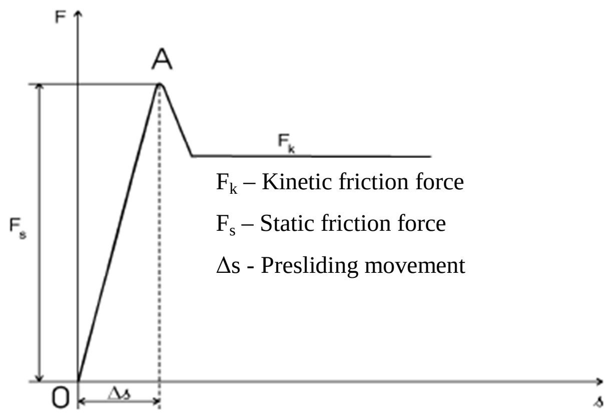

Fig. 1. Static and kinetic friction.

Under permanent conditions and even for the same material the coefficient of static friction value is not a constant and may vary in a certain range. The alteration of friction coefficient values is mostly stochastic, so one can only speak about the mean values of the friction coefficient.

Friction coefficient values depend on different parameters such as: nature and properties of the used materials, contact pressure value, thickness and type of surface film, contact surfaces roughness, duration of the contact, chemical interaction, presence of external bodies in the contact area, cleanness of contact surfaces, temperature of the surrounding environment, relative humidity, elasticity etc.

3. MEASUREMENT OF SLIP RESISTANCE

Nearly 11,000 workers suffered serious injury as a result of a slip in 2007 in Great Britain [8]. A key element of HSE's (Health and Safety Executive) work to reduce slips and trips is to raise awareness of how slip risks can be controlled through the use of suitable flooring and footwear. Research by the Health and Safety Laboratory has shown that a combination of factors contribute to slip accidents. There are the following influencing factors: floor, contamination, footwear, pedestrian factors, cleaning and environment.

Footwear suppliers use a variety of terms to describe their products, as like as 'slip-resistant', 'anti-slip', 'improving grip performance' etc. and these can often mislead customers. Slip-resistant industrial footwear will normally have been tested according to European standards, but many manufacturers and suppliers do not give helpful additional information, such as the degree of slip resistance and the types of work environment for which their products are most suited.

The aim of the HSE's project [8] was to collect and assess the slips safety information/literature provided by flooring and footwear suppliers in 2008 in Great Britain. A significant proportion of flooring products (55 %) did not make any reference to slip resistance or provide any test data. No indication of slip resistance was given for 47 % of footwear products.

A review of flooring test data showed that 54 % was generated using the pendulum test (Fig. 2), 33 % using the ramp test (Fig. 3), 0.2 % using roughness measurements and 12.8 % was generated using sled-type test methods, which in the opinion of HSE, can provide misleading results in contaminated conditions. The type of test used from footwear suppliers are: RAMP test 46 %, SATRA test 40 % and HSL RAMP test 14 %.

The information provided by footwear and flooring manufacturers was not satisfactory. Many footwear manufacturers made vague claims suggesting slip resistance and did not provide supporting data. Many flooring manufacturers avoid making reference to slip resistance altogether and information is hard to find.

Recommendation of the HSE project [8] is that it was apparent that many suppliers did not consider slip resistance to be a selling point and did not place significant emphasis on it. Currently, it is very difficult to make comparisons between products due to the number of tests used and specifications quoted. Where test data is provided, very little explanation is given and the layperson could be easily confused or misled. Footwear and flooring suppliers should be influenced to place more emphasis on the slip resistance of their products, and to use more standardized ways of assessing slip resistance; this would allow customers to make comparisons and help them to select the most appropriate product for their needs.

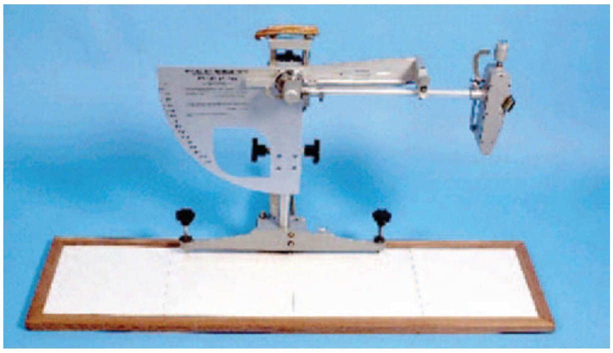

Fig. 2. The pendulum friction coefficient test.

Fig. 3. The ramp friction coefficient test.

Slip resistance properties of flooring materials and footwear are covered by various standards in Europe. Some of the most common are:

- BS7976 – British standard that describes the specification, operation and calibration of the Pendulum test, used for assessment of floor surface slipperiness under both dry and contaminated conditions.
- DIN51130 - Laboratory based ramp test, using cleated safety boots and motor oil contamination. Results are reported as an R value, on a scale from R9 to R13, with R9 being the least slip resistant.

- DIN51097 - Laboratory based ramp test, using barefoot operators with soapy water as the contaminant. Results are reported as Class A, B or C, with A being the least slip resistant.
- EN13845 - Laboratory based ramp test specifically for resilient floor coverings with enhanced slip resistance. The test uses standardized footwear and soapy water contamination.
- EN13287 - Laboratory based mechanical slip resistance test for safety / occupational footwear. The test uses several surfaces and contaminants to assess footwear.

Because of the nature of complexity and factors involved, the measured coefficient of friction quantities show inconsistencies even as the same shoe-floor combinations are employed. This fact has been recognized as a great concern when different friction testers, sensors and/or protocols are used worldwide.

However, variations of the coefficient of friction results under the same test environments have not received much attention in this research area. Despite of this fact, most slip safety researches have reported that a particular shoe or floor surface resists the movement of a particular floor surface or one's shoe sole across its surface.

4. EXPERIMENTAL RESEARCH OF THE STATIC FRICTION

Slip accidents can happen for a number of reasons: footwear, flooring, contamination and obstacles, cleaning, human factors, environment, etc. But footwear and flooring are the most important for tribological research.

Because of the existence of many different standards and methods for assess the slip resistance, measuring of friction coefficient on tribometer in laboratory condition is very useful. Footwear is produced most from rubber, because of its properties. The rubber is elastic, soundproof and it has low gravity density and good tribological properties.

Experimental determination of the static friction coefficient between samples of footwear soles and flooring were held on Mechanical Faculty in Niš. Static friction force can be measured only in the moment of sliding beginning for the reason that in next moment, after sliding start, this values falls on friction kinetic force value.

Experimental model for establishing static friction coefficient, projected for this investigation and which will be used for further investigation, is shown in Fig. 4.

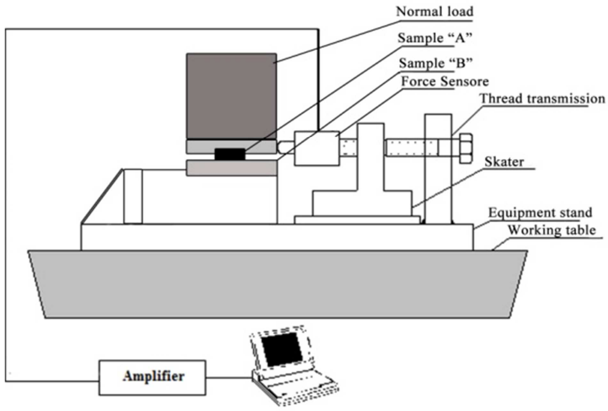

Fig. 4. Schematic review of device for measuring static friction force.

Measuring process was done so that by the turning the screw skater start sliding and force sensor fixed on skater pushes sample A (footwear sole sample). Sample A starts to slide on the sample B that is fixed in the base of device and pushing force is measured. Static friction force is established in the moment of sliding start.

Measuring system with experimental samples is shown in Fig. 5.

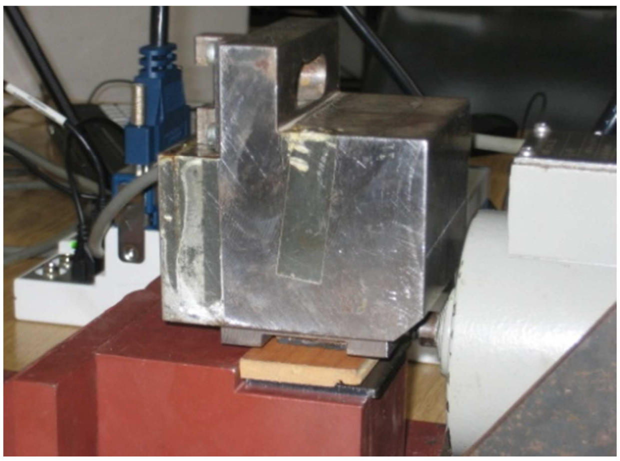

Fig. 5. Measuring system.

Samples used in this experimental investigation are with following characteristics:

- Footwear sole samples (sample A) are prism shaped and formed of soles cutout glued on a piece of chipboard. Nominal contact area is 30 mm x 30 mm = 900 mm^2. For this investigation there are four sole samples: new rubber with relief, worn (used) rubber with texture, new flat rubber and leather.
- For floor samples (sample B) are used plates of laminate, rough ceramic tile and smooth ceramic tile. Dimensions of plates are 60 mm x 75 mm according the measuring device.

Before testing all contact surfaces are cleaned with acetone. Floor samples surface roughness was measured by roughness measuring device Mitutoyo Surftest SJ-301. Roughness measuring gave the following results:

1. Laminate plate: R_a=0,9 μm, R_{max}=4,98 μm, R_z=3,25 μm,
2. Rough ceramic tile: R_a=12,85 μm, R_{max}=59,04 μm, R_z=43,93 μm,
3. Smooth ceramic tile: R_a=0,53 μm, R_{max}=3,44 μm, R_z=2,24 μm.

Measurements are done with weight (normal force) variations so that contact pressure was: 45 kPa, 79 kPa and 142 kPa.

Force sensor is produced by HBM, maximum force which can be measured is 500 N and sample rate is 100 Hz. For each contact combination five measuring were done. Contact surfaces are prepared in three ways: dry condition, wet condition and soap lubricated.

Tables 1, 2 and 3 show measuring results for static friction coefficient for different material combination and lubricating. Marks in the tables are: U1-new rubber with relief, U2-worn rubber with texture, U3-new flat rubber, U4-leather, P1-laminate plate, P2-rough ceramic tile and P3-smooth ceramic tile.

Table 1. Static friction coefficient of footwear sole samples and laminate floor sample (P1).

μ	U1/P1	U2/P1	U3/P1	U4/P1
dry	0,54	0,83	0,96	0,52
wet	0,39	0,66	0,67	0,65
soap	0,43	0,60	0,46	0,70

Table 2. Static friction coefficient of footwear sole samples and rough ceramic tile sample (P2).

μ	U1/P2	U2/P2	U3/P2	U4/P2
dry	0,52	0,47	0,54	0,63
wet	0,46	0,40	0,58	0,79
soap	0,38	0,54	0,39	0,77

Table 3. Static friction coefficient of footwear samples sole and smooth ceramic tile sample (P3).

μ	U1/P3	U2/P3	U3/P3	U4/P3
dry	0,25	0,69	0,44	0,47
wet	0,19	0,53	0,42	0,52
soap	0,11	0,22	0,13	0,50

Performed experiment shows that values of static friction coefficient are very unpredictable and random. Static friction coefficient of leather sample (U4) with presence of lubricants (water, soap) increases that is opposed of rubber samples with lubricants where coefficient of friction decreases. Very interesting results were in combination of rubber sample with relief (U4) and smooth ceramic tile, respectively measured static friction coefficient is very small (0,25 in dry condition until 0,11 lubricated with soap). That can be explained with small real contact area. Also, it can be conclude that for smooth ceramic tile coefficient of static friction is smallest for each sample.

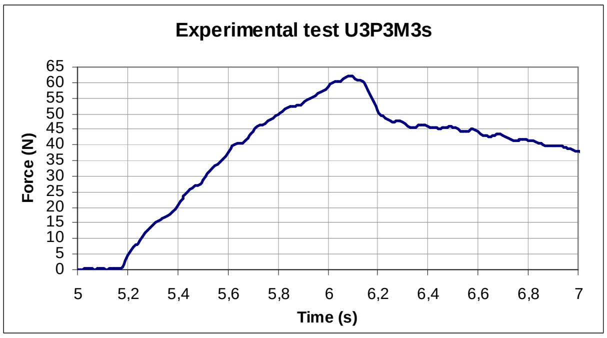

Fig. 6. Friction force-time diagram for flat rubber and smooth ceramic tile (normal load 131 N, dry condition).

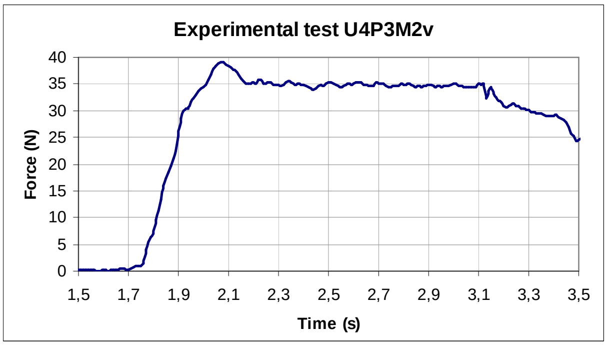

Fig. 7. Friction force-time diagram for leather and smooth ceramic tile (normal load 72,28 N, wet condition).

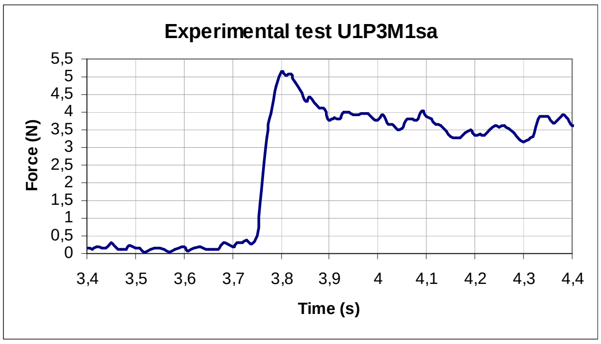

Fig. 8. Friction force-time diagram for new rubber with relief and smooth ceramic tile (normal load 41,82 N, soap condition).

Figures 6, 7 and 8 give the representative examples of recorded friction force in performed experimental investigation.

On the presented diagrams can be seen static and kinetic friction force when footwear sole samples slides over floor samples. Vertical axis represents force in Newtons and horizontal axis time in seconds. Diagrams show that friction force increases from zero value to the maximum value that is static friction force, and then falls to the kinetic friction force.

5. CONCLUSIONS

Due to the lack of static friction force in contact footwear-floor is often the reason for falls and injuries it is necessary to pay more attention in footwear and floor production in part of tribological properties. Certain standards about the slip resistance assessing are established in EU. Up to now in Serbia there isn't enough professional interest for this area, and it is left to the producers of footwear and floor.

Because of the existence of many different standards and methods for assess the slip resistance, measuring of friction coefficient on tribometer in laboratory condition is very useful.

According the importance of this problem and experience in earlier studies in the field of static friction, at Faculty of Mechanical Engineering in Niš is initiated research with the aim to determine tribological properties of rubber produces as footwear.

In that sense measurement of static friction coefficient between footwear sole and floor samples was performed. For that purpose it was designed measuring device for static friction estimation. Measuring results show that static friction coefficient is stochastic and unpredictable.

In further investigation it is necessary to improve measuring system and include more samples. Some samples should be industrial shoes and floors, tiles on public walkways, white stripes on pedestrian crosses the street and material other risky points where falls and accidents can happen.

REFERENCES

[1] I.J. Kim, H. Nagata: *Research on Slip Resistance Measurements — A New Challenge*, Industrial Health, Vol. 46, pp. 66–76, 2008.

[2] W. Brostow, V. Kovačević, D. Vrsaljko, J. Whitworth: *Tribology of polymers and polymer-based composites*, Journal of Materials Education, Vol. 32, pp. 273 – 290, 2010.

[3] N.K. Myshkin, A.Ya. Grigoriev: *Roughness and Texture Concepts in Tribology*, Tribology in Industry, Vol. 35, No. 2, pp. 97-103, 2013.

[4] N. Diaconu, L. Deleanu, F. Potecasu, S. Ciortan: *The Influence of the Relative Sliding on the Surface Quality*; Tribology in Industry, Vol. 33, No. 3, pp. 110-115, 2011.

[5] W. Yanzhong , W. Bin , W. Xiangyu: *Wet Friction-Elements Boundary Friction Mechanism and Friction Coefficient Prediction*; Tribology in Industry, Vol. 34, No. 4, pp. 198-205, 2012.

[6] M. Đurđanović, D. Stamenković: *Static friction causes movement*, in: *SERBIATRIB '07 – 10th International Conference on Tribology*, Kragujevac, Serbia 2007, pp. 215-218.

[7] D. Stamenković, M. Milošević, M. Mijajlović, M. Banić: *Estimation of the static friction coefficient for press fit joints*, Journal of the Balkan Tribological Association, Vol. 17, pp. 341-355, 2011.

[8] M. Liddle: *Assessment of slips safety information/ literature provided by flooring and footwear suppliers,* RR747 Research Report, Health and Safety Executive, 2009.

[9] R. Bowman: *Slip resistance testing - Zones of uncertainty*, Bol. Soc. Esp. Ceram., Vol. 49, pp. 227-238, 2010.

[10] D. Stamenković, M. Milošević: *Friction at rubber-metal spring,* in: *SERBIATRIB '09 – 11th International Conference on Tribology*, Belgrade, Serbia, 2009, pp. 215-219.

[11] HSE: *Assessing the slip resistance of flooring,* A technical information sheet published by the Health and Safety Executive, 2012.

[12] D. Stamenković, M. Milošević: *Experimental investigation of Static Friction,* in: *International Conference* ''POWER TRANSMISSIONS '03'', Section III "Experimental Investigations and Applications", Varna, Bulgaria, 2003, pp. 67-69.