Serbian Tribology Society

University of Belgrade,
Faculty of Mechanical Engineering

11th International Conference on Tribology

SERBIATRIB '09

PROCEEDINGS

EDITORS: Aleksandar Vencl, Aleksandar Marinković

May 13 – 15, 2009, Belgrade, Serbia

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Preface

The International Conference on Tribology – SERBIATRIB, is traditionally organized by the Serbian Tribology Society every two years, since 1989. The previous conferences were held in Kragujevac (1989, 1991, 1993, 1999, 2005 and 2007), Herceg Novi (1995), Kopaonik (1997) and Belgrade (2001 and 2003). This year the 11th International Conference on Tribology – SERBIATRIB '09 takes place on May 13-15, 2009 in Belgrade.

This Conference is organized by the Serbian Tribology Society (STS) and the University of Belgrade, Faculty of Mechanical Engineering. Organizing Scientific Conferences, STS plays a significant role in helping engineers and researchers to introduce in the fundamentals of tribology and to present their experience, solutions and research results. In the frame of the Conference a worth while jubilee: 15 Years of Serbian Tribology Society, which was in 2007, will be laid out with an appropriate publication of the STS history and activities (in Serbian).

The scope of the 11th International Conference on Tribology – SERBIATRIB '09 embraces the state of art and future trends in tribology research and application. The following two aspects of tribology practice require special attention. Firstly, the requirement for higher productivity of machinery means that machines must operate under higher loads and at higher speeds and temperatures, and that is why finding the right solutions for tribological processes is extremely important. Secondly, the good tribology knowledge can greatly contribute to the saving of material and energy.

The Conference program generally includes the following topics: fundamentals of friction and wear; tribological properties of solid materials; surface engineering and coating tribology; lubricants and lubrication; tribotesting and tribosystem monitoring; tribology in machine elements; tribology in manufacturing processes; tribology in transportation engineering; design and calculation of tribocontacts; sealing tribology; biotribology; nano and microtribology and other topics related to tribology.

All together 69 papers of authors from 19 countries (USA, Taiwan, Russia, Belarus, Ukraine, Slovakia, Germany, Austria, France, Netherlands, Italy, Slovenia, Bosnia and Herzegovina, Romania, Bulgaria, Greece, Turkey, Iraq and Serbia) are published in the Proceedings. Approximately 38 papers were submitted by the foreign authors and app. 31 papers by the Serbian authors. All papers are classified into seven chapters:

- Plenary lectures (5)
- Tribological properties of solid materials (12)
- Surface engineering and coating tribology (9)
- Lubricants and lubrication (8)
- Tribology in machine elements (8)
- Tribology in manufacturing processes and other topics related to tribology (11)
- Trenje, habanje i podmazivanje (16) – papers written in Serbian language

It was a great pleasure for us to organize this Conference and we hope that the Conference, bringing together specialists, research scientists and industrial technologists, and Proceedings will stimulate new ideas and concepts, promoting further advances in the field of tribology. The Editors would like to thank the Scientific and the Organizing Committee and all those who have helped in making the Conference better. We would like to thank especially prof. Branko Ivković and prof. Aleksandar Rac for the helpful suggestions and support.

The Conference is financially supported by the Ministry of Science and Technological Development of the Republic of Serbia, CSM Instruments, Serbian Chamber of Commerce, Messer Tehnogas AD, Oil Rafinery Modriča, Technology Transfer Center Hanover and RAR Batajnica.

We wish to all participants a pleasant stay in Belgrade and we are looking forward to seeing you all together at the 12th International Conference on Tribology – SERBIATRIB '11.

Belgrade, May 2009

Editors

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TRIBOLOGY AS ONE PARAMETER NECESSARY FOR RELIABILITY ENGINEERING AND TECHNICAL SYSTEM'S RELIABILITY IMPROVEMENT

Miroslav M. Mijajlović[1], Dragan S. Milčić[1], Miroslav B. Đurđanović[1]
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Abstract: *One trend in industry is to create integrated technical systems with significant and incre... degree of automation with decreased price of maintenance. The reliability of systems/elements is therefo... increasing importance since failures of technical systems may result in safety risks for people, soc... environment and can cause significant material, energetic and financial loses. Tribology has an impo... role in a large scope of reliability engineering and data determined by tribology-based methods ... fundament for reliability improvements. Different tribology-based methods help ease design, life... determination, condition monitoring and diagnostics. Reliability engineering uses knowledge, data ... assumptions from the tribology to get necessary information and improve reliability of systems. One of... major challenges for tribologists is to produce qualitative empirical data of interacting components ... system to support actions for improved reliability. This symbiosis of tribology and reliability req... dynamic connection between tribology and reliability as a must for reliable design.*

Keywords: *Tribology, Reliability Engineering, Reliability, Design*

1. INTRODUCTION

Industrial era had dramatic development of the technology and engineering so product of this development is development of the technical systems. This development started with development of simple machines and mechanisms, than was followed with the development of the plants and finally informational era has forced this development in the area of informatics and artificial intelligence application to the technical systems.

Technical systems are necessary and almost unavoidable for modern human society and their development is an after effect of society's growing hunger for energy consumption, speed, precision, manufacturing etc.

Unfortunately, this development created an opened loop which human kind still cannot finish and find a unique solution: more and more complex demands of society fulfill with application of more and more complex technical systems, which consist of more and more complex subsystems and components, which beside pure mechanical parts have electronic components and software. Ab... all there is still a human being, responsible for ... of the functions and reactions of the system, ... matter is it a simple personal computer, aircra... nuclear power plant.

These systems are complex, they are in ... cases very expensive for maintenance and ... eventual failures, beside material and econo... loses, might be enormous safety risk for h... society and environment.

Development of the technical systems infl... the need for information about oper... condition of the system, about information h... adjust system to stay operational and how ... prevent unwanted situation – failure of the sy... It become necessary to make conclusions abo... system based on the facts that appeared, to ... conclusions about operational condition of ... system, to predict for how long will an... system keep its operational abilities in the tol... limits and keep maintenance fees minimal. A... clusively, it appeared that several engineering ... of interest had to make a symbiosis with ...

...tific areas and create new engineering ...aches in order to make sustainable systems, ... global to micro level, as well.

...e of several scientific-engineering areas, ...oping side by side with development of ...ical systems is reliability engineering. ...ility is defined differently, from various ...ts, but most common definition, applicable to ...chnical systems, says that reliability is ability ...chnical system to maintain and fulfill its ...ed function in limits projected by developer ... system. Another, probabilistic definition says ...eliability is probability of none-failure work ... defined working conditions.

...liability and reliability engineering started its ...ion during and right after World War II. ... war technical systems required from humans ...p them in operational condition, as long it ...ssible. Otherwise, people would lost their ...nd properties.

...ability engineers use tolls, techniques and ...ility theory to give their judgment about ...echnical system and to design technical ... within proper operational limits. ...nately, reliability engineers are almost ... if they do not posses adequate data about ...n of the system they analyze. They directly ... data received from maintenance engineers, ...ists etc. and they use their methods to ... adequate data about the system.

...tenance engineers acquire data about the ... by measuring and observing parameters of ...em – noise, vibrations, cracks etc.

... someone analyzes friction, wear, or ...ion, it is unavoidable not to come to the ...y, scientific area that describes friction, ... and lubrication mathematically and ...ly. Since friction, wear and lubrication are ...portant parameters for the system with ...parts, they are directly responsible for the ...pe of failures. Tribology is one of the most ...t parameters for reliability estimation and ...ent. Understanding tribology helps ...ding operational condition of the systems, ...y or lifetime.

...logy has various levels of observations and ... various tribology based methods that ...p reliability improvement.

... LEVELS OF TRIBOLOGY

...ng tribology to the technical systems' ... is very important and responds to the ... demands of technology, industry and ... However, it is a great challenge to scale ...p the knowledge on the friction, wear and ... mechanisms from tribological analyses, done with tribo – tools like tribometers and microscopes are, to components and systems that can be as large as airplanes or paper nuclear power plants. Tribology has several levels that size up tribological data to the level applicable into the reliability engineering.

Tribology today has another trend, which is to go to smaller and smaller sizes in the investigation of friction and wear phenomena. Nanotribology is of increasing interest for tribologists and here the scales are coming down to the very basic dimensions of physical elements such as atoms and molecules are. In some cases, even the smaller area – to subatomic levels. Emerging new technologies have recently opened the possibility to study friction and wear phenomena on a molecular scale and to measure frictional forces between contacting atoms at a nano level. Increased computational power has made it possible to study friction and associated phenomena by molecular dynamic simulations of atomic-scale contact mechanisms. Nanotribology also called molecular tribology because investigations concentrate on phenomena related to the interaction between molecules and atoms. The increasing understanding of the tribological phenomena on nanoscale creates the need to scale up our nanoscale knowledge to conclusions on improved prediction of friction and wear that takes place on a more macroscopic scale, such as in practically observable everyday life.

Contact or macro – tribology was in focus in the research at the beginning of the 20th century. These works are related to contacts between gears, bearing elements and rollers, phenomena like Hertzian contact pressure, elastohydrodynamic lubrication, and wear mechanisms clearly observable by the naked eye (scuffing, scoring, pitting).

Component tribology or decitribology relates to defining and measuring typical parameters originating from the interaction of components and relates to their performance such as torque, forces, vibrations, clearance and alignment.

Machinery tribology or unitribology describes the performance – related phenomena for a system of components assembled in a machine or a piece of equipment. The parameters of interest are performance, efficiency, reliability and lifetime estimation.

Plant tribology or kilotribology deals with a whole system of machinery, structures and equipment – and now parameters such as economy, risk levels, availability and lifecycle costs are considered.

National tribology or megatribology extends the effects and consequences from the nationwide perspective, with the parameters of relevance such as safety policy, research policy, transportation policy and environmental policy.

Global tribology or gigatribology considers the effects on a worldwide basis as one interacting system; the effects that concerned about sustainable development, politics and cultural and human survival.

Universe tribology or teratribology is the largest perspective and considers tribological influence on the cosmic objects, like planets and stars are. Figure 1 shows tribology level.

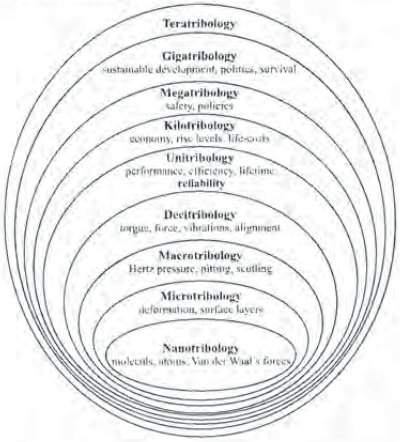


Figure 1. Tribology Levels

Without any doubt, any level of tribology can influence reliability of a system so active and dynamic connection reliability – tribology must be present. There is no adequate method for scaling results from tribology to reliability acceptable data. That is one of the biggest challenges for tribology and reliability engineers, to find a unique and for any branch of science, acceptable results.

3. RELIABILITY IMPROVEMENTS WITH TRIBOLOGY METHODS

There is a large scope and variety of techniques based on expert knowledge capable to analyze reliability and maintainability problems of a system from the basic point of view to the satisfied user of the system. Systematical approaches aim to improve dynamical connection between the different fields involved in the analysis by showing logical and comprehensive structure of the system and problems that may appear with system.

First step of the systematical approach is to identify critical parts of the system, calculate probability of the system failure, lifetim[illegible] operability costs etc. Methods that can evaluate th[illegible] are reliability methods, based on probability theo[illegible] and statistically based techniques. When the critic[illegible] parts of the system, which need improvements, [illegible] identified, it is necessary to identify critic[illegible] function or functions. In most of the cases, m[illegible] critical functions are products of bad lubricatio[illegible] wear and friction. Critical functions have to ran[illegible] from "low inflective" to "highly inflectiv[illegible]". Complete operability analysis of the influenc[illegible] component express in the following order: previo[illegible] solution analysis, a robust lifetime design appro[illegible] to recommended improvements, an analysis of th[illegible] new solution and the improvement actions w[illegible] estimated improved failure probability and prob[illegible] lifetime.

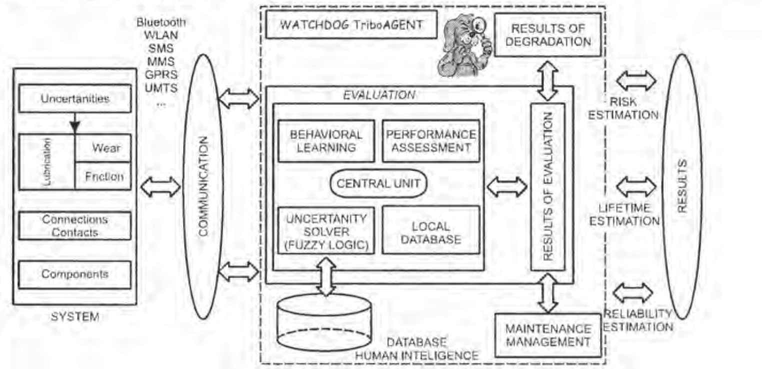
The outputs from the systematic approach [illegible] recommendations for improvements with meas[illegible] that engineers have to do on the system. The[illegible] measures are changes on the system, impro[illegible] design, extended monitoring, remote diagno[illegible] inspections, operational tests, proact[illegible] maintenance etc. However, it is not easy at all [illegible] find optimal solutions for a system. Complexity [illegible] the system requires systematic approach [illegible] components analysis and application of quantit[illegible] measures. It is almost impossible to make a uni[illegible] technique applicapable to every system, [illegible] reliability engineers have very challengeable ta[illegible] find adequate and optimal technique for prob[illegible] solving and than solution for problems. They [illegible] to use all the scientific and technical fields [illegible] basis, what complicates problem further more.

Scheme of systematic approach to the [illegible] lifetime and reliability estimation is in Figure 2.

Reliability engineers have very complex de[illegible] from other engineers: provide us precise and [illegible] information about the system that we are de[illegible] with and we will give you precise and [illegible] information about your system, its behavior [illegible] predict future condition of it.

On the other hand, tribology engineers [illegible] very difficult task to provide better tribologica[illegible] of interacting components to support actua[illegible] reliability improvement. Three basic tribolog[illegible] phenomena are friction, wear and lubricatio[illegible] all of them are reliability related. Friction bet[illegible] every two moveable components in any sy[illegible] result in energy and material loses and fina[illegible] failure of one or both components and failu[illegible] system. Wear is unwanted and almost unsto[illegible] process of material deterioration that resul[illegible] failure of component or complete system, if pr[illegible] last long enough. Lubrication is one efficient [illegible] to control friction and wear. Third material, [illegible] has good anti – friction and anti – wear abil[illegible]

[illegible]rted between interacting moving surfaces to [illegible]ease friction and wear, and directly reduce energy and material loses and help avoid or, at least, prolong failure.



[illegible]re 2. Systematic approach to the risk, lifetime and reliability estimation (Watchdog Agent is trademark, protected name of an infotronic system [2])

[illegible]om the point of view of a reliability engineer, [illegible]t important to find minimal value of friction [illegible]ient for improved reliability. Problematic [illegible]n is when friction coefficient goes over the [illegible]al value what creates higher values of [illegible]al forces. If friction coefficient increases, [illegible]al forces may cause damage to the system or [illegible] can stop its functioning. It is the same [illegible]n with low wear problem. Problem occurs [illegible] the wear rate exceeds values specified by [illegible]r. Result of this exceed are geometrical [illegible], tolerance changes, hazardous movements [illegible]lures.

[illegible]bility analysis needs better tribological data [illegible] component lifetime, critical wear, friction, [illegible]esent level of lubrication. Component [illegible] or endurance life is time until the [illegible]nt or the system can longer perform its [illegible] function or time when reliability of the [illegible] reaches value slightly above or precisely [illegible] designed lifetime, from tribological point [illegible] define as time until cumulative wear, or [illegible] friction coefficient or lubrication level [illegible] exceed critical value.

[illegible] are at least four applicable methods of [illegible] the required tribological data needed for [illegible] of reliability estimation:

- [illegible]ting historical data about similar [illegible]nents, their behavior and performance in [illegible] or slightly different situations.
- [illegible] generic knowledge of tribological [illegible]or in theoretical models, simulations and [illegible]ons.
- [illegible] laboratory tests of components and [illegible].
- Online monitoring of tribological performance and making a pattern of behavior.

Huge amount of knowledge and experience can be gained from similar components former behavior and pure with pure observations of the component. Problem might be difference between former behavior and present behavior. Besides complete understanding of the former component behavior, there are still numerous uncertainties that cannot be expressed as binary - YES/NO, 1/0, IN WORK / IN FAILURE etc, and they create significant non-precise conclusions and results. Another problem might be non-systematic collection of the data. Industrial era was era of fast growth and had no time to spare for systematic collection of data about component's behavior. Data has been collect only when there was a legal note about it or some other specific need.

Typical problem about data collection is that data was collect manually and by person responsible for the component/system and the task, it performs. That data is subjective and usually non-precise since consequences for bad results might influence future of the responsible future. This is overcoming as considerable uncertainty, but only within some limits. Otherwise data can be unusable or to subjective for serious application.

As possible solution for the objective, data gathering consider exclusion of human influence from historical data collecting and creation of automotive condition and operation monitoring modules that will collect data systematically.

Generic knowledge about quantitative friction and wear, based on the current tribological, mathematical and state of the art techniques is relative. There is a huge variation in the level of accuracy. Some areas have very precise and mathematically formulated models, but some have no adequate models at all. For example, there are very precise mathematical models for elastohydrodynamic contact pressure but there is no adequate mathematical model for estimation of friction with a presence of contaminated fluid as lubricant.

Praxis shows that usage of generic knowledge might be a method that will give uncertain results. Usage of existing knowledge is necessary, but appropriate mathematical model might be the problem. Only possible solution is to create specific friction and wear model for component or system that is being analyze. This might be long process and require from tribologist to be familiar with the component/system.

The most reliable method for tribology data collecting is laboratory testing. It is essential to plan an experiment correctly, use correct adequate and precise measuring equipment and know what the purpose of results is. Experiment has to repeat several times, to get as much as it is possible reliable results.

Online monitoring is the most expensive but very accurate method of data collecting. System is functional and monitoring system is gathering data about its functionality. If system is automated, human imprecision and subjectivity is exclude. Since this method requires dramatically higher price of the monitored system, such a method requires complete analysis from economic point of view for every system.

4. DESIGN FOR RELIABILITY

The most of design methods in use today base on calculations, static or dynamic load and durability analysis. New tools, recently developed, also take into account the reliability aspects in design. Reliability-based design method is one relatively new tool that might help design for reliability. This method enables the effective prediction of the reliability of a product in explicit form right at the design stage. This method provides a design with the means to judge new and innovative ideas based on their predicted reliability, and it helps to focus on the right target with reliability engineering efforts. This model-based simulation approach starts with building up a fault tree for the product. The possible failures estimate and classify according to the best, mean and worst cases of probable occurrence. The fault tree forms the basis for the reliability simulation base on failure data, diagnosis and prediction models. In the case of wear or friction-related failures, the estimation of the probability to appear during certain periods in the lifetime of the component and the estimation of the probable endurance lifetime bases on the best available tribological data. These data obtain from historical data analysis, from theoretical models, from laboratory-produced data, or with usage of artificial intelligence. If there is a suspect about objectivity or precision, artificial intelligence, with usage of fuzzy logics and neural networks can give suitable results for reliability improvement

Finally, this chapter emphasizes the importance of the tribology society to produce friction and wear data for different material combinations, as well as in different contact and environmental conditions in the form of endurance life or probability of failure in precise and for reliability engineers suitable manner. The data can then be of use in reliability estimations and functional predictions of components and systems since reliability engineering depends on data gathered by other scientific areas.

5. CONCLUSIONS

Reliability engineering is modern and relatively young area of science and it is still in evolving phase. It has achieved tremendous success in engineering and found application in almost every technical science. Fortunately or unfortunately, reliability engineering is useless without other areas of science. Data is the main basis of every reliability analysis, lifetime determination or reliability design but reliability engineers cannot collect data nor create mathematical model that can provide it.

Tribology is one of the essential scientific areas for failure understanding in every system, since friction, wear and lubrication are almost unavoidable in every technical system. The tribological understanding of friction and wear mechanisms and the generation of reliable friction and wear data, as example, for different material combinations and operational conditions is of great importance for the determination of the reliability of systems. To be of real value, the tribological data must be expressed in the terms acceptable and understandable for the reliability engineers.

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