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ELASTOMERS IN COAL INDUSTRY. SAFETY PROBLEMS

Abstract. Usage of elastomeric materials in the coal industry is considered in context of creation of new high-performance machines for the latest technology of mining, processing and enrichment of mineral raw materials, such as coal. Specific advantages of elastomers - great reversible deformation and high dissipation properties– are described that make the elastomers a valuable structural material for such products as tires, rollers, conveyor belts, vibration isolators, protective lining, elastic links, etc. Basic achievements in the field of mechanics of elastomers, development trend of modern machinery designs with elastomeric elements are considered, and promising use of the elastomers in the coal industry is presented.

Keywords: elastomeric materials, coal industry, vibroinsulators, protective linings, safety

Entering the third millennium, most of scientific schools summarize their researching efforts and determine their role in total world scientific achievements made in the twentieth century. They publish a lot of retrospective reviews and generalizing monographs and hold numerous symposiums, conferences, meetings and other scientific forums.

Within this context, important scientific results obtained by Ukrainian researchers should be mentioned as they have contributed a lot into the sphere of theoretical and applied mechanics and deformable body mechanics, in particular. Special attention should be paid to their findings in the field of mechanics of new structural materials including composites and nanomaterials to which elastomeric elements (rubbers and polyurethanes) are referred which, in their turn, are currently widely used providing successful development of the machinebuilding and coal industries [1, 2].

The elastomers, due to their chemical composition and good elastic properties, essentially differ from any other structural materials by their better dissipative characteristics and excellent ability for reversible deformation. As they are more like biomaterials a lot of researchers call them a material of future. Today, the elastomeric elements are successfully used in many items produced by the machinebuilding industry: tires and conveyor belts, vibration isolators and protective lining, elastic elements and sealers, home appliances and special products – this is a long but not full list of products in which elastomeric materials can not be adequately replaced by any other existing material.

Developmental level of the modern machinebuilding industry is estimated by the number of elastomers used in the industry as the industry motto today is: an up-to-date design of any machine should comply technological requirements (approximately up to 2030) through its improved operational life and reliability.

It is the elastomeric elements - vibroinsulators, flexible links, protective linings – which being implemented into of any machine design can ensure reduced vibration intensity, effective sound pressure, longer operational life and higher reliability. Actually, each technical engineering achievement in any industries including coal production is associated, in this or that degree, with the usage of elastomeric elements as structural material.

Mechanics of Elastomers. Question of the Day.

Ukraine has attained a lot in designing structural materials for different industries showing general scientific values which have greatly effected the industry as a whole and engineering in particular and created a sound basis for further industry development. However, some serious problems and drawbacks are obvious.

Today, a necessity of further improvement of elastomer mechanics is a question of the day, and this necessity is closely connected with a problem of total machinebuilding development including production of machines for the coal industry.

The improvements of elastomer mechanics advances further development of Ukrainian fundamental and applied science and its great future.

Without radical improvement of the elastomer mechanics it is impossible to overcome some urgent problems as some industries will not be able to be normally developed.

There is a strong confidence that the opinion expressed in these theses is shared, in this or that degree, by majority mechanic scientists in Ukraine.

Mechanics of Elastomers. Up-To-Date Concepts and Development Prospects.

Intensification of current operations in the Ukrainian coal industry has required creation of new technologies and modernization of existing and designing of new machines. Requirements to the power intensity and metal consumption, machine reliability and operational life duration and ecological requirements have become essentially stronger. On the other side, a trend of more intensive operation of machines results in greater stress, wearing, harmful vibration etc. Taking into consideration specifics of the operations, the problems were overcome in different ways: by creation of principally new machine design, usage of new structural materials, changes of technologies, etc. Only one concept – a concept of further introduction of flexible connecting elements (vibroinsulators, compensators, wear-resistant coats and linings, flexible spacers, dampers made of such elastomers as rubber and polyurethane) - was never changed in the whole machinebuilding industry. It appeared that elastomers were a perfect structural material, and in some cases (for example, in vibratory bearings and seismopads, spring linkages, spacers, etc.) they could not be replaced by any other existing material.

The result was that a somehow complicated situation had occurred. Practice pressed for usage of elastomeric structures (ES), however, foreign experience was not available enough, existing rubbers did not feature the desired properties, no experimental equipment was in sight. Mechanics of material deformation and fracture was developed but mainly for metals and partially for the rigid plastics and did not take into account such specific properties of elastomers as ability to great reversible de-

formation, intensive dissipation energy, instability of elastomer properties in the timeline (aging), etc. Besides, in order to create a real elastomeric structure it was necessary to solve, additionally to the theoretic problems, a series of applied problems: technology for the ES manufacture, optimal ES design, the ESs protection against external corrosive environment and their interaction with machines (problems of machine dynamics), etc. I.e. the problem was needed to be solved generally on the interface between the science and engineering basing on the comprehensive approach which should include the following stages: fundamental researches – experiment – applied researches – optimal designing - development of new rubbers – development of the products – machines with ES. At the same time, realization of such approach was restricted by absence of any experimental information and experimental equipment.

Therefore, the following problems had to be solved in the first place.

Methods and facilities were created for the experimental studying of the ES physical and mechanical characteristics on the basis of own developments plus foreign nonconventional experiment methods and unique apparatuses made by such companies as MTS, Instron and others from Japan, Germany, USA.

Comprehensive experimental information was received in result of studying the ES rheological, thermotechnical and fatigue characteristics under widely varied stress regimes and conditions for interacting between the ES and environment which were quite typical for machines operating at metallurgical works with extreme conditions of exploitation. Frequency rate covered nine orders (10-3 – 106 Hz); temperature was within 223 - 473 K; environment was in the form of hard ionizing radiation with absorbed dose 0-200 Mrad; operational life curves for the full-scale ESs at their cyclic operation till a destruction were got within 107-4,9*109 cycles. The findings include unique data on how the aging impacts the rubber rheological and fatigue properties, operational life and dissipative self-heating, and disclose positive role of dissipation in the cyclic ES fracture.

For prototypic models, the obtained information concerned micro-fracturing processes at cyclic loading; with the help of IR method, kinetics of microfracture accumulation in the volume and on the surfaces of the samples was specified; role of a surface in total mechanism of fracturing (concentration of microfractures in the thin surface layer with thickness of 1-2 mcm increased 2-3 orders quicker than in the volume) was defined; at cyclic loading, the kinetics of microfracture accumulation complies with the first-order equation where velocity constant depended on stress, temperature and radiation dose; local exothermal effects were studied with the help of IR-radiometry and it was stated that thermodestruction temperature could reach 480K in the crack mouth.

Main lawful description of the cyclic destruction mechanism was established for the full-scale ES models: kinetics of the fatigue crack development was explained for different states of material (depending on damage rate, radiation dose, degree of the structure changing due to the structure filling, etc.); micromechanisms of fracture were studied and key factographic peculiarities were specified; a self-healing effect (crack stopping) was detected and role of energy dissipation in the fatigue crack de-

veloping and stopping was disclosed including interaction between the ES destruction mechanisms and rheology at different states of the material structure under impact of external environment; mixed role of energy dissipation in the total mechanism of the ES fracturing was revealed.

All above mentioned helped to: develop the ES destruction criteria; formulate common requirements to the elastomers with taking into account a dissipation-fracture interdependence and specific conditions of the ES exploitation; create phenomenological models of the ES fracture for different mechanisms of the cyclic destruction.

Following the obtained experimental information, it became possible to create mathematical models, fracture criteria and methods for the ES life prognosing under multi-factor impact of stationary cyclic loads and external environment: an energetic criterion of a dissipative type was created and grounded for the isothermal conditions as well as analytic expressions for calculating the ES operational life by their coordinates; a destruction criterion was created by cracking developing in the material, and expressions for prognosing the ES operational life were formulated; engineering methods were worked out and now are widely used for calculating the ES for different machines.

Theoretical basis for this study was fundamental principals of continuum mechanics, thermodynamics of irreversible processes and some concepts of synergy and catastrophe theory with the help of which a lot of applied problems were solved. Key condition for the successful solving of these problems was that true properties of concrete materials were taken into account.

This set of theoretical and experimental studies and obtained scientific findings made it possible to realize, in general, a program of extensive applied researches (including researches on elastomer technology, optimal synthesis of new rubbers, dynamics of machines with rubber elements, optimal ES designing) in combination with engineering practice.

First of all, it is necessary to mention creation of short-module rubbers (protected by the inventor's certificate on the elastomers, first in the USSR) made of domestic polyizoprene caoutchoucs. These rubbers exceeds all existing world analogues by their life duration, stability of properties in the timeline (resistance to aging) and resistance to radiation.

Using these rubbers and rubbers of other grades the original ES were designed: blocks, hinges, vibratory bearings, couplings, insulators, vibrating insulators, seismopads, protective linings, etc. Most of them are protected by the inventor’s certificates and for some of them the industry standards were worked out. Totally, more than 12 types of the ES were designed (each type includes parameters series of 2-10 items). In general, they are used in all types of heavy vehicles of general purpose, some of them are equal to the best world analogues by their properties and life duration.

The designed ES, by-turn, promoted up-grading of old and creating of new machines. Thanks to specific properties of the new rubbers (high fatigue strength, good resistance to aging, great reversible deformation), it became possible to design an up-to-date class of vibration machines (conveyors, screens, feeders) with fundamentally

new technological modes – high amplitudes and low frequencies; 2-3 times increase output; reduce up to 30-50% metal consumption due to replaced steel springs and carriage springs by the rubber elements; cut sound pressure, etc.

Among numerous engineering applications of the ES in machinebuilding and other industries three key segments should be singled out.

The first of them refers to a class of machines with ES designed for progressive technologies covering a total complex of mineral (including coal) extraction and processing. One of such technologies is associated with the machines (vibration feeders, vibrating hoppers, conveyors, screens) designed for material output and delivery. Another technology covers processing, separation, crushing, hermetic transportation and other technological operations for which the following machines with ES are designed: conveyors, crushers (KID and others), vibrating screens, feeders, etc. – totally about 20 production vehicles.

The second segment refers to the ES application with the aim to reduce vibratory stress in existing machines which are mainly operate in mining and smelting industry and coal production: special crushers, pelletizers, vibrating troughs, vortex mixers, fans, etc. The following products can also be referred to this segment: protective linings for wagons and carriages, protective linings for vibrating feeders, damping elements for high-frequency vibration, etc. In all these cases, the ESs make machine life longer, cut sound pressure, reduce impact loads and wearing, etc.

The third segment is associated with designing of vibratory bearings and seismopads installed in foundations of various buildings, houses, bridges and so on. It is the ESs which help to essentially reduce hard consequences of natural and man-caused catastrophes.

Generally, the achievements above can be considered as a first stage in creating a competitive line.

Further essential efforts are needed both in the field of fundamental researches and for solving applied problems.

Summarizing the above, the most important issues should be mentioned.

Trend of the modern industry development is to include the following viscoelastic elements into schematic diagrams of machines, mechanisms and objects: vibrating insulators, sealing elements, dampers, protective linings, etc. A material they are made of is elastomers – rubbers and polyurethane with unique properties: simple processing technology, good resistance to aggressive media, high fatigue and reliability, great dissipation, ability to great reversible deformation and relatively low costs. In some cases (tyres, vibrating insulators, seismosupports, linings) the elastomers can not be adequately replaced by any other existing today material.

The elastomeric structures can: 2-3 times increase machine productivity due to the intensified processes; reduce (by up to 50%) metal consumption; ensure 2-10 times better operational life and reliability; reduce vibration stress and seismic stress in machines and objects; create fundamentally new machine designs.

Among the reasons of domestic machinebuilding lagging is insufficient usage of the elastomers in spite of the fact that Ukraine has everything for intensive development of such important for the Ukrainian economy aspect.

In Ukraine, fundamental and applied mechanics is traditionally well-advanced thanks to the powerful scientific, technical and industrial potential in such branches as mechanical-rubber and tyre production and tire repairing which is able to meet demands inside and outside the country.

The following works have been already made in the coal industry:

1. Parametric series were created for the rubber and rubber-metal vibrating insulators of BP and BPM types. The vibrating insulators of BPM type (DSTU 3853-99 (GOST 30644-99) – International Standard «Rubber Vibrating Insulators for Explosionproof Fans») are used as elastic suspension for the explosionproof fans.

These vibrating insulators passed industrial acceptance tests for various types of technological machines. Their usage essentially (by 1,5÷2 times) increased operational life of the key assemblies and parts of machines, decreased dynamic loads on the structures, intensified technological processes and lowered in-plant noise.

2. Rubber lining was created for the mine wagons transporting sticking weights.

Design of the rubber lining is protected by a patent (by the inventor's certificate No. 1063675), and it passed tests in uranium mines (city of Zholtye Vody), at enterprises of Uralzoloto (Ural Gold) Company and in Russian coal mines.

Operations of the wagons show 95% degree of the wagon cleaning, decreased dynamic loads on the running gear, increased haulage effectiveness, and provided a possibility to abandon existing vibrating and mechanical cleaning of wagons with solid bottom.

3. Original vibration-isolation systems were created for and implemented into parametric series of the hammer crushers (of the ДМРЭ type) and inertial crushers (of the КИД type). These crushers are widely used for crushing coal at the chemical-recovery enterprises. The parametric series of the КИД crushers with the vibration-isolation systems designed by the IGTM, NAS of Ukraine, are commercially produced by the Russian enterprises and are exported to many countries of the world. The Institute has designed vibration-isolation systems for four hammer crushers ДМРЭ 14,5×13 for the "Zaporozhcoke" Company which are currently at the stage of implementation. The Institute also designed for and commissioned at the "Dneprodzerzhinsk KHZ" Company a vibration-isolation system for the crusher ДМРЭ 1000×1000 usage of which resulted in reduced vibrating loads on the overlapping surfaces and neighbouring objects up to the levels even lower than those which are permitted by the sanitary code.

4. A device with vibration-isolation bottom was designed for the belt conveyors (both district and trunk) in order to prevent the belts from being cut. At the moment, more than 200 devices are in use, and thanks to them it becomes possible to almost entirely exclude longitudinal cuts of the belts.

Solving of the problems above provides promising challenges for realizing a lot of practical task, namely:

- to create new highly reliable and effective machines for coal industry: screens, feeders, conveyors, centrifugal machines, crushers, sieves, etc. designed for alternative friendly-environmental technologies;

- to provide longer operational life, higher reliability, less metal consumption and energy intensity and higher wear resistance for the machines and equipment;
- to protect machines and objects (bridges, industrial buildings) against vibration, in-plant noise and seismic loads in order to prevent the breakdowns and natural or man-caused catastrophes.

Realization these tasks is the strongest business case for the Ukrainian industry with its well-developed raw material, machinebuilding and energetic bases and intensive construction of industrial buildings and objects.

Issues on industrial safety. One of the reasons of increased number of accidents in Ukraine is a high percent of obsolete technologies and worn fixed assets. Thus, tear and wear of the production facilities in all branches of Ukrainian economy is 50% and even more in some of them.

Among these branches is Ukrainian mining and smelting industry which is "oversaturated" with the obsolete complicated systems tear and wear of which is 80%, hence, a risk degree here is very high. These systems include: various ore-crushing mills, crushers, vibrating screens, pelletizers, mixers, vortex mixers, smoke suckers, ventilators, etc. These machines are of heavy weight (10-300 tons), operate with large-sized materials, have unbalances moving systems, are installed on the overlapping surfaces, and structurally, they themselves present a source of vibration. All such machines together with the infrastructure of other manned technical facilities produce complicated "man-machine" systems which, due to certain objective reasons, have a low level of reliability, and their installation in areas with a great concentration of population makes the risk of accidents and natural or man-caused catastrophes extremely high. A breakdown of a single such machine can present a man-caused major disaster following with stopping of entire technological chain and economic losses. And a breakdown of a group of such machines can be resulted in a man-caused catastrophe.

Risk factors for such machines are as following:

- permanently and long acting vibration loads caused by operation of technological equipment resulting in destruction of equipment, foundations, bearing columns and other engineering objects especially under the impact of active external environment;

- intensive abrasive wear (lining in ore-crushing mills) resulting in frequent lining replacement in the working sections of the drums and the drum drives destruction;

- intensive sound impact (noise pollution resulting in injury).

Vibration of any vibrating machine harmfully effects people and an operator in particular. The vibration protection is one of the most important scientific and technical problems which can be overcome only if a system (man – machine - environment" (the "m-m-e system") is entirely studied.

Specificity of a safety object is determined by an objective complexity of the m-m-e system consisting of some complicated and interdependent components and behavior purposefulness and stochasticity of each of such component. The latter specificity assumes that behavior of such components as man and machine could be unex-

pected under random environmental impact and due to extremely unstable own parameters. The uncertainty is worsen by the fact that the output characteristics of one component of the systems can be an input impact for the others.

Basing on all above mentioned, and in order to ensure safety of the system, a resume can be made that it is necessary to apply approaches oriented to the special-purpose program.

Besides, the problem requires consideration of a lot of scientific and social factors. Below are some of them which refer to critical object (CO) safety:

1. The COs usually include enterprises of mining and smelting industry (mines, ore- pits, concentration plants, color ore processing plants, cement production lines, etc.); buildings and objects located in seismic regions and regions under the explosion and vibration actions; machines and complexes with intensive dynamics loads; etc. All such machines and objects feature low-frequency vibration of great intensity: usually, the low-frequency vibration is within 0.2-25 Hz, and the most dangerous frequency for a man-operator is within 0.2-50 Hz.

2. The problem of safety functioning of the COs, infrastructure and personnel is a strong business case not only for Ukraine and the CIS but also for industrial countries of the world.

3. The CIS countries adopted an international program for united scientific researches in the field of extreme situations caused by nature and people activity till 2020. Such well-known institutions as Theoretical Engineering Institute (Moscow), Institute of Strength Problems and Mechanics Institute of NAS of Ukraine (Kiyv), IGTM of NAS of Ukraine (Dnipropetrovs'k) and others are involved to the work under this program.

4. The COs safety is estimated by analyzing their functional processes, state monitoring, modeling and estimating failure risks and evaluating losses and is provided by development of the effective safety strategies.

Analysis of the COs development trends shows that the risk of accidents in result of direct action of different unfavorable factors will be increased in future. This problem is complicated by the absence of any unified complex approach to estimation of the COs safety. Each branch of a human activity operates with own instrumentation and concept of the safety estimation. However, different understanding of the problem leads to variety of methods applied for estimating the COs safety.

5. The critical objects can exist separately but, actually, they are components in the complicated technical system (CTS).

Systemic studying of the CTS safety and reliability began in the world 30-40 years ago mainly in the field of aerospace and nuclear industries, however, during the recent years the study covers chemical, mining-and-smelting, coal, transport and other industries which could present a danger for the community. Today, the CTS safety and reliability theory is a far-advanced science based on the powerful and diversified mathematic apparatus. Thanks to cross-the-board usage of computers methods of the safety and reliability theory will be spread to the widest circle of engineers, designers and constructors as soon as the nearest future.

6. Totally, the research methods applied in the safety theory and reliability theory are much the same and factually nonseparable. The both theories differ rather by their purposes than by their facilities. The reliability theory purpose is to provide operability of any system, and the safety theory purpose is to maximally eliminate technical dangers. As any safety CTS should be reliable as well, then it could be concluded that a problem of reliability provision is a component of the safety problem.

7. Analysis of the existing literature on the CTS safety and reliability states that the most reasonable, fruitful and promising orientation for solving this problem is an approach which is based on the risk analysis, and in order to ensure reliability effectiveness it is necessary to add it by a theory of the safety control with optimal combination of technology of accident prevention (minimization) and technology of the accident effect elimination.

In this case, the effective safety control can be provided by minimal total costs and optimal cost distribution between the technology of the accident prevention and technology of the accident effect elimination on the understanding that both technologies provide system stability (a zero final risk).

8. Priority scientific developments providing safety for and protection of population, environment and objects against natural and man-caused catastrophes include the following:

- to create methods and criteria for estimating safety and risks both in man-caused and natural-man-caused environment;
- to create and develop integral methods for protection against natural and man-caused accidents and catastrophes with taking into account possible technological terroristic actions;
- to create and develop scientific and methodological basis on a platform of multicriteria approaches of the safety theory.

9. Today, it can be stated with great confidence that one of the most common causes of the accidents and catastrophes is harmful vibrations of man-caused and natural-man-caused character (seismic excitations are one of the cases of vibration loads). It refers, in the first place, to the CSs at enterprises of mining-and-smelting industry where permitted sanitary engineering norms can be exceeded twice and even trice.

10. One of the orientations for solving problem of protecting personnel, machines, equipment, foundations and building structures against effect of greatly intensive vibration loads (including low-frequency spectrum of their action) is a development of principals for choosing parameters for the vibration isolation systems and usage of elastomeric (rubber and rubber-metal) elements in designs of these systems.

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