ISSN: 0975-8585

Research Journal of Pharmaceutical, Biological and Chemical Sciences

Development of A Test Rig for Research into Ultra-High-Speed Collisions Between Liquid Droplets and A Metal Surface.

Alexey Feliksovich Mednikov*, Alexander Ivanovich Bychkov, Gennady Viktorovich Kachalin, and Alexander Borisovich Tkhabisimov.

National Research University "Moscow Power Engineering Institute", Krasnokazarmennaya str., 14, Moscow, 111250, Russia.

ABSTRACT

The authors depict the design, principle of operation and main components of a test rig intended for research into the droplet impact erosion. This equipment enables conducting erosion tests in a vacuum at a speed of collision between a sample and a monodispersed or polydispersed flow of liquid droplets of up to 800 meter per second; at the same time the dynamics of destruction of the surface layer by droplets can be visualized thanks to high-speed photography techniques.

Keywords: Steam turbines, erosion, test rig, ultra high-speed droplet impingement.

Corresponding author

INTRODUCTION

In recent times turbine manufacturers tend to increase the power output of turbine units through increasing the length (> 1200 mm) of the blades of the last-stages of low-pressure cylinders that operate with saturated (wet) steam [1,2]. During operation such ultra long blades (that are currently being developed) are exposed to large loads due to droplet impingement; collisions of droplets with the entrance edges that occur at ultra high speeds (up to 800 meters per second) lead to destruction of the blades. Therefore one has to take measures in order to protect the blades (that are currently being developed) against drop impact erosion that occurs when the pressure and temperature are increased to higher levels.

Turbine manufactures and researchers all over the world have gained a certain level of knowledge about various types of wear and tear of components of power equipment and methods of their protection [3-5, 6, 7]. Metallurgists have eventually developed solutions to problems relating to the use of wear-resistant structural steels and alloys that are for the most part designed and suitable for sector-specific applications. Unfortunately, expensive materials are not cost-effective because of the frequent replacements and repair of the components of equipment operating in harsh conditions. That is why there is an urgent necessity to create and use new high-strength materials and versatile protective coatings and develop various methods of modification of functional surfaces that would efficiently improve the wear resistance and in particular the erosion resistance.

When tackling this problem, one has to understand the physics underlying the processes that actually speed up the pace of erosion, analyze the features and characteristics of the chosen methods of surface protection and assess their influence on said pace of erosion. Researchers and engineers all over the world keep this in mind and search for solutions that would strike a compromise between conflicting requirements imposed on surface and volumetric properties. Today efficient methods of protection against erosion can be developed only based on a comprehensive research into the influence of the characteristics of the created coatings on the kinetics of erosion of building materials and their erosion resistance.

Both in Russia and abroad there were numerous studies [8-11] dealing with creation and properties of novel wear-resistant building materials, novel protective coatings and various methods of modification of functional surfaces [12, 13] to be used in many sectors of the [electric] power industry, but, unfortunately, although the methods of protection against erosion are numerous, not many of them can be used and are capable to withstand harsh conditions. It is noteworthy to mention that one of the main barriers to successful development of new technologies of protection of the surfaces of building materials against destruction is the absence of adequate test equipment that would allow designers to adequately assess the proposed solutions.

Today the main kinetic patterns associated with high-speed liquid droplet impingement and thought to be responsible for erosion of various materials are already known thanks to the use of hydraulic test rigs and theoretical computations [14, 15]. Researchers have identified the key parameters influencing this process: particles' speed and incident angles, their size and also the hardness and the microstructure of the materials under investigation [16, 17]. Most of the studies deal with the measurement of the relative erosion resistance of various metals and coatings. A significantly lower number of studies reveals the underlying physical processes and influence of the properties of coatings and/or patterns of modification of the surface on the erosion patterns. The results of the studies that are available today [18, 20] do not allow to clearly identify the mechanisms that are responsible for erosion damage incurred by the 'coating-substrate' system in case of a high-speed (up to 800 meters per second) collisions between liquid particles and metal surfaces. In order to reveal such mechanisms one should conduct further experimental research into the influence of various characteristics of the methods of protection of surfaces on the kinetics of the processes responsible for erosive wear and properly generalize the available experimental results and theoretical conclusions.

Today the development and upgrading of hydraulic rigs is predetermined because of the necessity to create heavy-duty power equipment that would operate in extremely harsh conditions at elevated pressures and temperatures of the working fluid. One should upgrade the existing test facilities through creation of novel test rigs simulating the high-speed collision between liquid droplets and a metal surface and this measure will allow to obtain unique scientific results and develop new technologies of protection of heavy-loaded components of power equipment and in particular blades of last stages of low-pressure cylinders.

In order to solve this problem the «National Research University «Moscow Power Engineering Institute» has launched a project for the creation of a novel ultra high speed test rig that has no analogs in the world: it will allow investigating the erosion of turbine blade materials with modified surfaces and/or various types of protective coatings when the speed of collision between the liquid droplets and the surface can vary up to 800 meters per second. The results of these tests will for the first time in the history allow to identify the main features of the influence of characteristics of various methods of protection on the kinetics of erosion.

DESCRIPTION OF TEST RIGS AND TEST FACILITIES

Both in Russia and abroad various types of test facilities are used in order to simulate the development of erosive wear of those stages of turbines that operate with wet steam [21-31]. However, such test facilities are not suitable for a comprehensive simulation of operating conditions. Nevertheless tests conducted with the use of such facilities allow to promptly assess both the erosion resistance of materials exposed to droplet impingement and the influence of the conditions at which collisions occur (first of all, the relative collision speed and size of the impinging liquid particles) on the pace of erosion. The results of such tests are used by those who develop new computational methods or measure & assess the relative resistance of materials showing its dependence on the relative collision speed and size of the impinging particles.

In the world there exist over 15 test facilities for simulation of the erosive wear and assessment of the influence of various parameters on the pace of the destruction of metal surfaces. In particular, the following companies and universities have already accumulated such kind of experience, have expertise and possess necessary software and hardware: «Alsthom», «Hitachi», «Mitsubishi», «ABB», «Siemens», university of *Stuttgart* (Germany), «National Research University "Moscow Power Engineering Institute» (Russia), university of Limerick (Ireland), SAAB (Sweden), Center for Innovative Developments in Ottobrunn (Germany), university of Hiroshima (Japan), Voith Hydro (Germany), etc.

A common design of such test rigs/ stands includes a rotating disc or a rotating arm and one or up to several dozens of tested samples attached to its peripheral zone. Their circular trajectories intersect zones where the samples collide with liquid droplets or a liquid jet. In such facilities the circumferential speed (in this case it is equal to collision speed) is in the range from 50 to 600 meters per second, and the diameters of droplets (or jet) is in the range from 0.1 mm to 15 mm. Today there exist many methods of producing liquid droplets of various sizes. In most facilities droplets are produced through the controlled or uncontrolled breakup of the stream from the tip of a capillary.

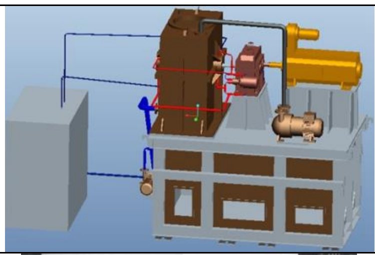
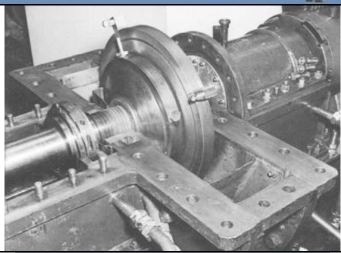
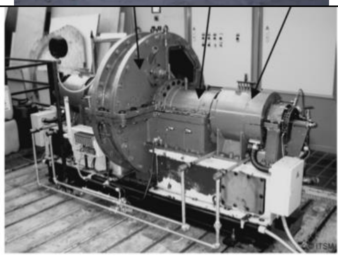
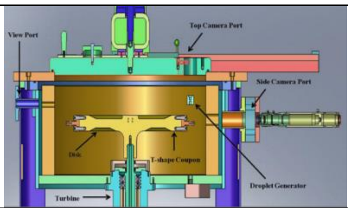
In this case the collision speed is a function of rotational speed and the rotation radius of the arm. In most test facilities the relative velocity between the surface of a sample and a droplet is perpendicular to the surface.

The test rigs and facilities enable modeling of a single collision or multiple collisions between a sample and a stream. In case of a single collision a projectile carrying the sample in its frontal part is ejected into the liquid droplet that is hanging motionless or falling down or, just the opposite, the sample is motionless and it is the liquid jet that is ejected. In order to simulate multiple collisions one uses ‘fogs’ (cloud of liquid droplets) produced by various devices (nozzles, pulverizers, etc.) or separate liquid jets or ‘chains’ of monodispersed droplets.

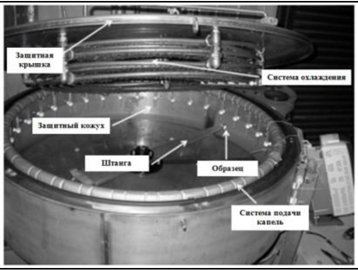
Table 1 presents key parameters and photos of test facilities used in Russia and abroad for research into droplet impact erosion. Although these test facilities do not allow to exactly simulate the processes occurring in natural conditions in every respect, they still allow to conduct research into the erosion of metal surfaces of rotating blades and other components of turbines in a short time for a fairly low cost.

ISSN: 0975-8585

Table 1. Test facilities for research into droplet impact erosion of materials

Organization	City, country	Photo/ appearance /mounting layout	Maximum collision speed, m/sec	Kind of liquid (size, mm)
Shanghai Power Equipment Research Institute	Shanghai, China		180	Jet (-)
C.A. Parsons and Company	Newcastle, UK		610	Droplets (0,09 ÷0,11)
Corporate R&D Division (BHEL)	Hyderabad, India		147,6	-
Institute of Thermal Turbomachinery at the University of Stuttgart	Stuttgart, Germany		660	Droplets (0,08 ÷ 0,09)
University of Montreal	Montreal, Canada		500	Droplets (0,4 ÷ 0,6)
Doosan Skoda Power	Czech Republic		600	Droplets (0,15 ÷ 0,4)

ISSN: 0975-8585

Organization	City, country	Photo/ appearance /mounting layout	Maximum collision speed, m/sec	Kind of liquid (size, mm)
University of Limerick	Ireland		176	Droplets (2)
SAAB	Sweden		300	Droplets (1,2 ÷ 2)
Center for Innovative Developments	Ottobrunn , Germany		225	Droplets (0,8)
«National Research University "Moscow Power Engineering Institute»	Moscow, Russia		600	Droplets (0,02 ÷ 1,2)

Development of a ultra high-speed test rig

The unique ultra high speed erosion test rig that is currently being developed must enable conducting erosion tests in a vacuum at a speed of collision between a sample and a monodispersed or polydispersed flow of liquid droplets of up to 800 meter per second; at the same time the dynamics of destruction of the surface layer by droplets or clouds of droplets must be visualized thanks to high-speed photography techniques.

When designing the erosion test rig the authors took into consideration the many years' experience of operation of similar equipment and applicable standards.

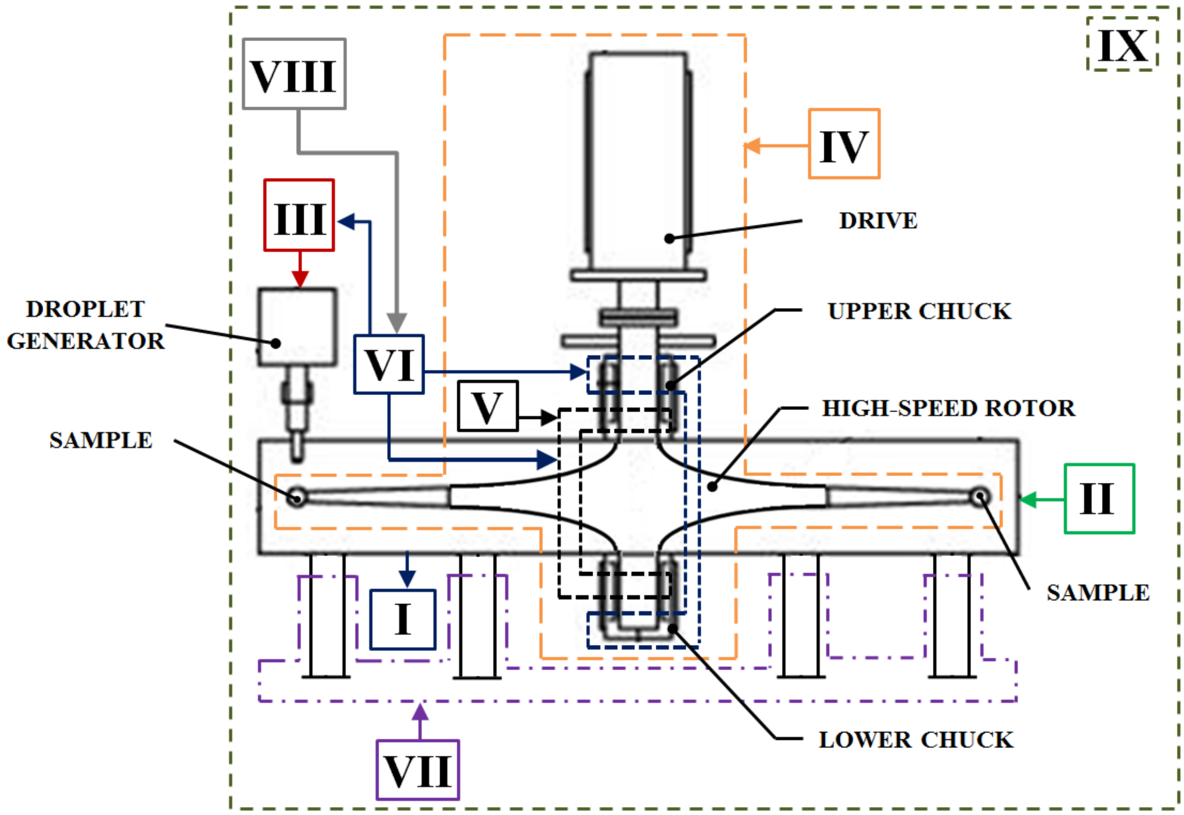
The ultra high speed erosion test rig is designed to meet the following requirements:

- collision speed between the liquid droplets and the tested samples: up to 800 m/sec;
- rotational speed of the airfoil arm – over 12 000 revolutions per minute;
- pressure in the chamber of the erosion test rig – not more than 10±0.1 kPa;
- generation of mono- and polydispersed flows of droplets from 50 to 1500 µm, cloud of droplets with typical size from 10 µm to 500 µm.

Fig. 1 shows the already developed functional layout of this test rig that includes:

- a vacuum pumping system for pumping air and water away from the chamber (I);

- high-speed photography system (II) enabling visualization of the process of destruction and transformation of the surface tested and collisions with liquid droplets or their clouds;
- a system for preparation of water (III) for generation of mono- and polydispersed flows or clouds of droplets in a special generator;
- a system enabling high speed rotation (IV) comprising a high-speed rotor, cooled upper and lower chucks with forced lubrication, a high-speed drive (with a cooling system and a control system);
- a system for lubrication of the chucks' bearings (V);
- a cooling system (VI);
- an anti-vibration system (VII);
- an external cooling system (VIII);
- a system for automated control and data processing (IX), including monitoring and measuring equipment (vibration sensors, temperature sensors, pressure sensors, etc.) and enabling remote control.

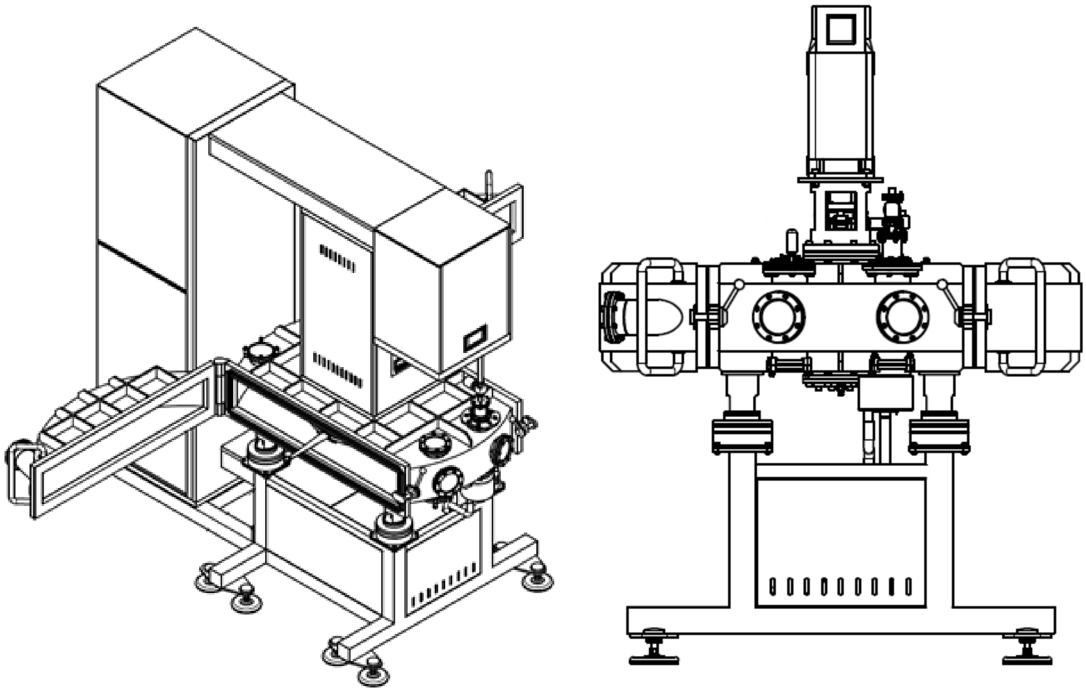


I - a vacuum pumping system for pumping air away from the chamber; II - high-speed photography system; III – a system for water preparation; IV – a system enabling high-speed rotation; V – a system for lubrication of the chucks' bearings; VI – a cooling system; VII – an anti-vibration system; VIII- an external cooling system; IX - a system for automated control and data processing.

Figure 1. Functional layout of the ultra high speed erosion test rig

At the stage of concept design the chosen concept of the test rig is a completed structural design designating all of the main components that are to be assembled together. Figure 2 shows the appearance of the assembled test rig (that is being developed) and its appearance without housing and control system.

The erosion tests consist of periodical interaction between the tested sample and a flow of a liquid (a jet, droplets, etc.). In order to achieve the necessary speed of the sample it is rotated. The sample is attached to the end of an arm mounted on a high-speed rotor. Another arm with another sample is mounted on the same rotor diametrically opposite to the first arm. The rotor is vertically mounted inside a vacuum chamber and is driven by a special high-speed drive. The flow of liquid is formed by a droplet generator that is located in the outer part of the chamber. The process of interaction between droplets and the surface of a sample is recorded by a high-speed video-camera; for this reason the butt and lateral surfaces of the vacuum chamber have inspection holes.



a) b)

Figure 2. Appearance of the assembled test rig (a) and its appearance without housing and control system (b)

The main component of the rig is the vacuum chamber with a rotor inside it. The rotor's drive is located in the upper part of the chamber. The chamber has two doors located opposite to each other for enabling access to the internal part. The chamber's workspace can be fit inside a cylinder with diameter of 1320 mm and height of 200 mm. A strength analysis and stress calculations have shown that the thickness of the lateral and upper walls should be equal to 10 mm. For adding stability to the chamber's shape the lower and upper surfaces have reinforcing ribs. The size and spacing of these ribs have been calculated with the use of a software package. The 12Cr18Ni10Ti corrosion-resistant steel has been selected as the material for the chamber's housing. The droplet generator is located in a special slot in the upper part of the chamber. The inspection holes for the recording equipment are located on the frontal and upper parts of the chamber. A module for feeding liquid to the droplet generator is placed on an isolated box above the droplet generator. The droplet generator control panel is located on the frontal panel of the box. The rotor's drive is placed inside a casing; the synchronization sensors, accelerometer sensor and arrays of temperature sensors and pressure sensors are placed in the same casing. The module for control and monitoring of key parameters is also located on the frontal panel. The automated control module is placed on a special support in the rear part of the test rig. The camera is placed on a support that is equipped with an anti-vibration system. The exhaust station is placed in the internal part of the bottom platform. All components of the test rig are interconnected through conduits, channels and chutes that route technological tubings and cables.

A high-speed rotation system enables achievement of rotational speeds of up to 1400 revolutions per minute so that the sample's speed is not less than 800 m/sec. This system is comprised of a high-speed drive, cooled upper and lower chucks with forced lubrication, a high-speed rotor with special arms to which samples are attached, and a drive controller. The torque is transmitted from the drive to the rotor through a flexible pin bush coupling.

The upper and lower chucks are equipped with coolers because of the high emission of heat that is transferred from the rotor shaft to the bearings. The cooling system provides adequate cooling for all of the main components of the test rig. Figure 3a shows a schematic diagram of the cooling system. The cooling system includes an expansion tank, a circulating pump, an outlet collector, heat exchangers and control,

ISSN: 0975-8585

monitoring and measuring modules. The cooling liquid is pumped away from the expansion tank with the use of the above-mentioned pump; then it is pumped through the heat exchanger of the outer system and enters the outlet collector. From there the liquid is fed to all of the components that need to be cooled. Different components emit different quantities of heat. For this reason the consumption of the fluid is regulated with the use of controllers that are installed in all of the chains. Upon passing through proper component the liquid passes through measuring units and a flow relay and then enters the intake collector from there the liquid passes to the expansion tank. The water circulating through the cooling system is cooled in the heat exchanger that is connected to an external water feeding system.

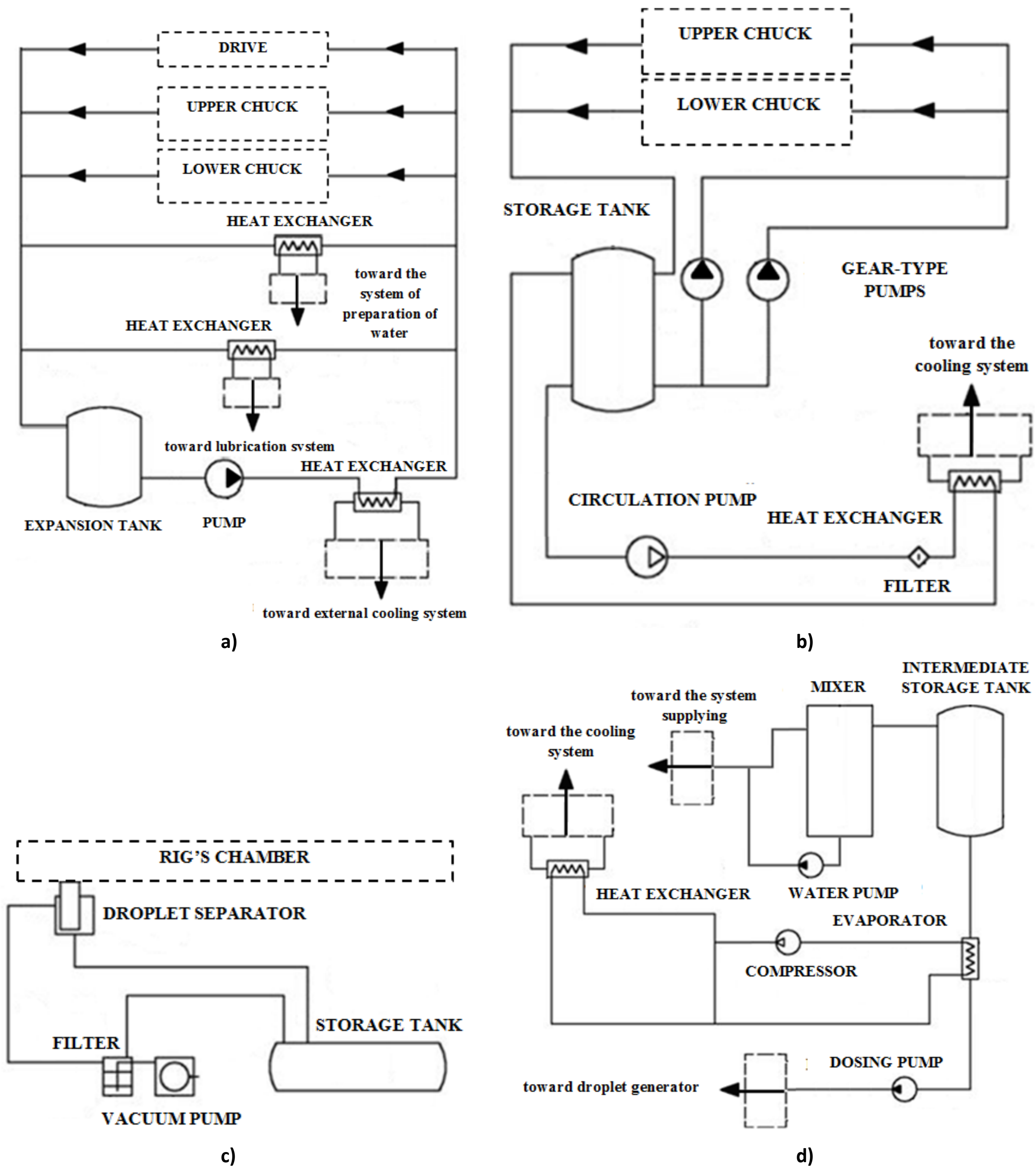


Figure 3. Schematic diagrams of the main systems of the erosion test rig that is currently being developed: a) cooling system; b) lubrication system; c) vacuum system; d) system for preparation of water.

Figure 3b) shows a schematic diagram of the lubrication system. Purified lubricating oil is fed through four nozzles directly to the bearing cages. Such a lubrication scheme enables maintaining the lubricating oil film on work surfaces. Besides it, heat is partly transferred from the heated shaft to the lubricating oil and consequently the bearing are somewhat cooled. The pumps (located in the upper and lower chucks) pump purified and cooled lubricating oil from the first section of the oil tank to proper chucks. Upon quitting the chucks the lubricating oil enters the second section of the above-mentioned tank; after that the pump of the filtration system pumps the lubricating oil to the filter for its purification and then to the coiled heat exchanger for its cooling because the oil is heated when passing through the chucks. After cooling the oil is pumped back to the first section of the oil tank.

The vacuum pump system enables achievement of pressure down to 5 kPa in the vacuum chamber and maintaining the pressure at this level during tests. Figure 3c) shows a schematic diagram of the vacuum pump system. The vacuum pump system is comprised of an exhaust station and a unit serving as an interface with the vacuum chamber. The exhaust station comprises a vacuum pump, a storage tank and a filter. The vacuum pump is intended for pumping away mediums with high content of water vapor. At the pump inlet there is a filter for preventing the entry of solid particles into the pump. Large quantities of water will be released into the vacuum chamber during tests and adjustment of the operation of the test rig. A special system for droplet separation comprised of an interface unit and a storage tank is installed for removal and storage of this water. The droplet separator designed as a 'bottle siphon' and installed at the outlet of the chamber enables apportioning of water feeding it toward the storage tank container and the pumped medium (air + water vapor).

The system of preparation of water is intended for cooling and feeding the prepared service liquid to the droplet generator. Figure 3d) presents a schematic diagram of the system of preparation of water. The ready-to-use service liquid is pumped by the dosing pump from the intermediate storage tank to the heat exchanger, where it is cooled down to the temperature that is needed for the experiment and then it passes through the cutoff valve to the inlet of the droplet generator. The necessary temperature is maintained with the use of a thermostat that comprises a compressor. The compressor and the condenser are placed in the same module. A flow-control valve is placed directly on the evaporator; it is connected to the compressor as a split-system. A leak-free scroll compressor is used as a cooling compressor. The water is fed to the droplet generator with the use of a dosing pump. The later is a compact volumetric dosing pump with a diaphragm, whose rotational speed can be varied (step motor). Before being fed to the droplet generator the water is cooled in the heat exchanger that is located next to the dosing pump being assembled together with the flow-control valve in a single module.

The anti-vibration system damps the vibration occurring during the operation of the test rig in a wide range of frequencies. The system is mounted on a welded spatial frame; in the lower part of this frame there are eight shock mounts mounted on center plates; in its upper part there are four pneumatic vibration dampers for passive vibroisolation of the equipment in case of stationary vibrations or random oscillations. The vibrations are actively damped thanks to the measurement of the amplitude of pressure pulsations inside the chamber of a pneumatic vibration damper leading to pressure change in response to such pulsations. The greater the amplitude of the pulsations, the lower is the pressure.

The system of automated control of the rig is intended for the control of the rig's equipment, automated maintaining of the scheduled technical processes, storage of archived information about the behavior of the technological parameters during tests; it ensures the following:

- safe operation of the test rig;
- visualization of the information in a convenient format; display of the parameters characterizing the status, condition and operation of the test rig using a monitor;
- display of the information about the operation of the test rig for the entire period of its operation (text and/or graphic images); archiving of information on the technological processes, failures to meet technological standards, emergencies; report generation.

CONCLUSIONS

The authors have described the developed design of an ultra high speed erosion test rig and presented schematic structural diagrams with description of the main components, principle of operation and values of parameters that can be achieved during testing. The developed equipment (that has no analogs in the world) will allow to conduct erosion tests at the speed of collision between the samples and mono- and polydispersed flow of a liquid up to 800 meters per second and visualize the dynamics of destruction and transformation of both the surface layer and the impinging droplets thanks to high-speed photography techniques. Erosion tests that will be conducted with the use of this test rig will allow to study the erosion resistance achieved through various methods of reinforcement of metal surfaces and obtain fundamental scientific results as to assessment of the influence of ultra high speed droplet impingement on the characteristics of the surface and subsurface layer of the material of the sample and identification of the distinct stages of the processes of initiation and development of erosion.

The ultra high speed rig can be used for carrying out experimental designing and development of technologies for modification of surfaces and formation of erosion-resistant coatings for increasing wear-resistance of functional components of turbines operating at a high level of thermal and mechanical stresses and exposed to ultra high speed droplet impingement.

ACKNOWLEDGMENT

This research was supported by the Ministry of Education and Science of the Russian Federation under Agreement No.14.577.21.0180 dated October 27, 2015 (unique identification number RFMEFI57715X0180).

REFERENCES

[1] Leyzerovich, A.S. (2008). Steam turbines for modern fossil-fuel power plants. *Fairmont Press*, p. 529.
[2] Fukuda, H., Ohyama, H., Miyawaki, T., Mori, K., Kadoya, Y., Hirakawa, Y. (2009). Development of 3,600-rpm 50-inch/3,000-rpm 60 inch Ultra-long Exhaust End Blades. *MHI Technical Review*, Vol.46, No. 2, June.
[3] Kostjuk, A.G. (2005). Some urgent problems relating to design and modernization of steam turbines. *Thermal Engineering*, No. 4, pp. 17-22.
[4] Ulm, W. (2003). The situation in steam turbine construction and current development trends. *OMMI*, Vol. 2, Issue 3, December.
[5] Smiarowski, M.W., Rainer, L., Scholten, C. (2005). Steam turbine modernization solutions provide a wide spectrum of options to mprove performance. *Germany John Blake, Siemens Power Generation*.
[6] Pris, K. (1982). Erosion. *Mir,* Moscow, p. 464.
[7] Springer, G. (1981). Erosion caused by liquid droplet impingement . *Mashinostrojenie,* Moscow, p. 200.
[8] Lammela, P., Whitehead, A.H., Simunkova, H., Rohr, O., Gollasa Droplet, B. (2011). Erosion performance of composite materials electroplated with a hard metal layer. *Wear*, No271, pp. 1341–1348.
[9] Duraiselvam, M., Galun, R., Siegmann, S., Wesling, V., Mordike, B.L. (2006). Liquid impact erosion characteristics of martensitic stainless steel laser clad with Ni-based intermetallic composites and matrix composites. *Wear* No261, pp.1140–1149.
[10] Ahmad, M. (2009). Experimental assessment of droplet impact erosion resistance of steam turbine blade materials/University of Stuttgart. *Wear*, No267, 1605–1618. doi.org:10.1016/j.wear.2009.06.012.
[11] Luiset, B. (2013). Mechanisms of stainless steels erosion by water droplets, Laboratoire d'Etudes et de Recherches sur les Matériaux, France. *Wear*, No303, 459–464. doi:10.1016/j.wear.2013.03.045.
[12] Tobin, E.F. (2011). Comparison of liquid impingement results from whirling arm and water-jet rain erosion test facilities, University of Limerick, Department of Mechanical, Aeronautical and Biomedical Engineering, Limerick, Ireland. *Wear,* No271, Issues 9–10, 29 July, pp. 2625–2631. dx.doi.org/10.1016/j.wear.2011.02.023.
[13] Oka, Y.I. (2007). Effective parameters for erosion caused by water droplet impingement and applications to surface treatment technology, Department of Chemical Engineering, Hiroshima University, Japan. *Wear*, No263, pp. 386–394. doi:10.1016/j.wear.2006.11.022.
[14] Seleznev, L.I., Ryzhenkov, V.A., Mednikov, A.F. (2010). Phenomenology of erosion wear of constructional steels and alloys by liquid particles. *Thermal Engineering*, No. 57, Vol. 9, pp. 741-745.
[15] Luiset, B., Sanchette, F., Billard, A., Schuster, D. (2013). Mechanisms of stainless steels erosion by water droplets. *Wear*, No303, pp. 459–464.

[16] Mednikov, A.F., Ryzhenkov, V.A., Seleznev, L.I., Lebedeva, A.I. (2012). Studying the variation of parameters characterizing the material surface during the droplet erosion incubation period. *Thermal Engineering*, No. 59, Vol. 5, pp. 414-420.

[17] Hattori, S., Kakuichi, M. (2013). Effect of impact angle on liquid droplet impingement erosion. *Wear*, No298-299, pp. 1–7.

[18] Hu, H.X., Jiang, S.L., Tao, Y.S., Xiong, T.Y., Zheng, Y.G. (2011). Cavitation erosion and jet impingement erosion mechanism of cold sprayed Ni–Al2O3 coating. *Nuclear Engineering and Design*, No241, pp.4929–4937.

[19] Whitehead, A.H., Simunkova, H., Lammel, P., Wosik, J., Zhang, N., Gollas, B. (2011). Rain erosion characteristics of electrodeposited Ni–SiC metal-matrix composite layers. *Wear*, No270, pp. 695–702.

[20] Hu, H.X. (2011). Cavitation erosion and jet impingement erosion mechanism of cold sprayed Ni–Al2O3 coating, State Key Laboratory for Corrosion and Protection, Institute of Metal Research, Chinese Academy of Sciences, PR China. *Nuclear Engineering and Design*, No241, pp. 4929–4937. doi:10.1016/j.nucengdes.2011.09.038.

[21] Kumar, A., Singh, G., Singh, S. (2013). Impact of varying the nozzle stand - off distance on cutting temperature in turning of en-31 steel with minimum quantity lubrication. *International Journal of Research in Engineering and Technology*, Vol. 2, Iss. 06, Jun, pp. 931-936. doi:10.15623/ijret.2013.0206003

[22] F. Erdmann-Jesnitzer, H. Louis / Studies on cavitation damages // Erosion, wear, and interfaces with corrosion: ASTM Special Technical Pulication. – No 567. – 1974 - pp. 171-195.

[23] B. G. Mellor / Surface coating for protection against wear / Woodhead Publishing (e-book), - 2006 - pp. 68-72.

[24] http://web.tuke.sk/lmv/lmv2009/prezentace_pdf/LMV09_Kriz.pdf (A. Kříž, P. Beneš, J. Šimeček / Impact test of surface, Lokálne mechanické vlastnosti – 2009 – 19 p.)

[25] R. Chattopadhyay / Surface wear: Analysis, treatment, and prevention // ASM International. – 2001 - 307 p.

[26] ASTM G73-10. Standard Test Method for Liquid Impingement Erosion Using Rotating Apparatus; ASTM International: West Conshohocken, PA, USA, 2010.

[27] C. Moreau, A. Dolatabadi, M. Medraj M.S. Mahdipoor, F. Tarasi HVOF sprayed coatings of nano-agglomerated tungsten-carbide/cobalt powders for water droplet erosion application / Wear. – No 330-331. – 2015 - pp. 338-347.

[28] The influence of material hardness on liquid droplet impingement erosion / N. Fujisawa, T. Yamagata, S. Takano, K. Saito, R. Morita, K. Fujiwara, F. Inada // Nuclear Engineering and Design. – No 288. – 2015 - pp. 27-34.

[29] O. Gohardani Impact of erosion testing aspects on current and future flight conditions // Progress in Aerospace Sciences №47, 2011, pp. 280–303.

[30] M. Duraiselvama, R. Galun, S. Siegmannc, V. Wesling, B. L. Mordike Liquid impact erosion characteristics of martensitic stainless steel laser clad with Ni-based intermetallic composites and matrix composites // Wear №261, 2006, PP. 1140–1149.

[31] Y.I. Oka, S. Mihara, H. Miyata Effective parameters for erosion caused by water droplet impingement and applications to surface treatment technology // Wear № 263, 2007, pp. 386–394.

[32] State Standard (GOST) 23.219-84 'Ensuring erosion resistance of products. Methods of tests of erosion resistance of materials and components being worn due to hydroerosion caused by impingement by dispersed particles.