DOI: 10.1051/matecconf/201712901014

Modelling of destructive ability of water-ice-jet while machine processing of machine elements

Mikhail Burnashov[1,*], *Alexander* Prezhbilov[1], and *Elena* Stepanova[1]

[1] Orel State University of I.S. Turgenev, Orel, Russian Federation

Abstract. This paper represents the classification of the most common contaminants, appearing on the surfaces of machine elements after a long-term service.The existing well-known surface cleaning methods are described and analyzed in the framework of this paper. The article is intended to provide the reader with an understanding of the process of cleaning and removing contamination from machine elements surface by means of water-ice-jet with preprepared beforehand particles, as well as the process of water-ice-jet formation. The paper deals with the description of such advantages of this method as low costs, wastelessness, high quality of the surface, undergoing processing, minimization of harmful impact upon environment and eco-friendliness, which makes it differ radically from formerly known methods. The scheme of interection between the surface and ice particle is represented. A thermo-physical model of destruction of contaminants by means of a water-ice-jet cleaning technology was developed on its basis. The thermo-physical model allows us to make setting of processing mode and the parameters of water-ice-jet scientifically substantiated and well-grounded.

1 Introduction

The hydro jet technologies are widely used in industry. They are necessary for cuttingmaterials, cleaning contaminants off the surfaces of machine elements [1-20].

2 Problem description

During an operation of machine elements contaminants (which differ in kind, composition, properties and the strength of the adhesion to the surfaces of machine elements) are being formed on their outer and inner surfaces. These contaminants reduce the durability of machine elements, as well as their service life and resistance to corrosion.

When repairs are carried out, contaminants undermine labour productivity, make accuracy of monitoring and defectation of machine elements worse, reduce repair quality and resource of repaired machines and their elements.

The most widespread causes of contaminative coating formation include an emulsive and oil slick, an introduction of the contaminants from the environment, thermal decomposition of oils, an oxydation of metal surfaces, burnt-on (sticking) sand, oil remains, scale etc.

Contaminants on the objects under repairs are divided into the following types due to their chemical composition:

- organic (oil and fat deposit, varnish coating films, lubricants);
- non-organic (scale, road mud, corrosion products);
- mixed (carbon deposit, varnish, grease, industrial contaminants).

Contamination of plant items, assembly units and machine elements include:

- outer deposit,
- remains of lubricative materials,
- carbon deposit (building-up),
- corrosion products,
- scale,
- remains of old paint coatings.

The most common and widespread contaminants are remains of fuel-lubricative materials and products of their transformation. Drastic changes of lubricative materials, occuring during use of machines, are caused by the processes of ‘aging’-oxydation and polymerization. The following types may be singled out:

1. an incomplete combustion of fuel,
2. oxydation products,
3. products of destruction of hydrocarbons,
4. polymerization products,
5. products of condensation and coagulation of hydrocarbon and heteroorganic compound,
6. corrosion products and biodamage of metals in the medium of remains of fuel lubricative materials.

According to up-to-date state of the field under discussion the industrial processes must be environment-friendly, energy-efficient and meet industry needs and evolving governmental regulations. These demands are also obligatory for cleaning for the removal of contaminants from surfaces.

Water-jet \ cryo-jet methods are considered to be highly promising and universal methods of cleaning among existing ones.

*Corresponding author: stker@rambler.ru

At the same time, a hydroabrasive cleaning with sand and similar materials, performing the function of an abrasive, has a wide range of drawbacks. Let's mention some of them:
- the abrasive complicates cleaning of inner and inaccessible surfaces;
- roughening of clean surfaces;
- the necessity of utilization of the abrasive, contaminated during the blasting process;
- a high cost of an abrasive material and its delivery.

Therefore, renewal and replacement of the abrasive material is absolutely necessary for a wide introduction of hydroabrasive technology of cleaning of machine elements.

Furthermore, water-ice jet cleaning technology is not only an ecologically clean but also a cost-saving method.

Ice particles possess properties of hard particles, which allow them to remove a great deal of contaminants during accelerating to higher speeds and avoid causing damage to a base of surfaces, undergoing cleaning. Use of water and ice makes regeneration of clean media easier.

In comparison with other methods of cleaning, water-ice jet technology obtains some advantages:
1 minimization of harmful impact upon environment;
2 a low-cost cleaning materials;
3 an absence of the necessity to transport and keep large amounts of the abrasive material;
4 a possibility of a closed and waste-free cycle;
5 a reduction in an abrasive influence on material;
6 the abrasive does not block up peep-holes of machine elements joints;
7 an absence of dust in the cleaning process;
8 a high durability of an instrument.

A water-ice jet formation for cleaning machine elements surfaces is run in the following way: a highly pressured stream, having a diametre ranging from 0,15 to 0,3 mm, is being mixed with entrained stream of ice particles according to an ejection principle. As a result, a two-phased structure, called a water-ice jet, is formed. Use of ice particles, prepared beforehand, is preferable and optimal for this process. The size of particles varies from 1,5 to 2 mm (Fig. 1).

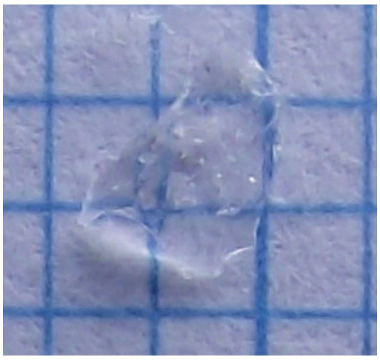

Fig. 1. The picture of an ice particle

Mechanism of coating destruction, caused by water-ice jet, is determined by a multiphase character of highspeed flow (water-ice particles) (Fig. 2).Having spent part of its energy on an acceleration of ice particles, water jet creates voltage, equal to its strength, in the material, which is undergoing destruction. At the same time, ice particles are making a full impact on the material, causing microcracks. They concentrate stresses, which enhances cleaning efficiency in general.

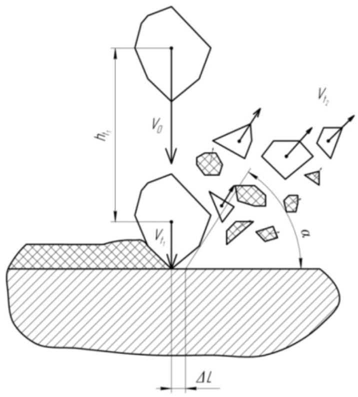

Fig.2. The scheme of an impact on removable coating of an ice particle and its destruction.

Economic efficiency is achieved in the process of deriving granulated ice by means of crushing ice lumps in industrial ice generators. During further mechanic crushing necessary fraction is separated from ice crumb. After production of working granulated ice with a help of this method, the model of an ice particle was created in the programming environment Compass-3D (Fig. 3).

Fig. 3. The scene of the model of an ice particle (an isometric projection)

3 Thermo-physical model of destruction

While being formed, water-ice jet may undergo the following phases:
1. A highly pressured water jet bursts from a stream-forming checkerwork, creating an area of low pressure in a plenum (mixing) chamber, where ice particles are being entrained from the supplying canal.
2. Water-jet-ice particles are entrained by a water flow and mix with it, causing an intensive heat exchange.

3. Mixture of water and ice particles is being accelerated in a collimator.

Energy is generated in the closed system 'an ice particle-a destructed material-machine elements' by means of impulsive force and interaction and is being transformed into a heat stream and a work of cutting. The definition of a fraction of energy, spent on heating an ice particle, accompanied by creation of local zones of reversed phase transfer (transmission) (RPT) of ice and heating of material, causes a particular interest.

Contaminating coatings have a low capacity for heat transfer, therefore, temperature of a contact surface 'an ice particle-material'will determine mechanic and thermal physical properties of material of coating.

The scheme of an interaction between the surface and an ice particle is represented in fig.4.

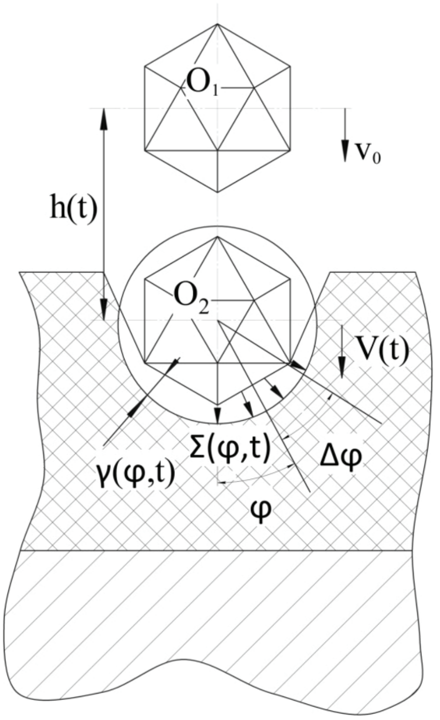

Fig. 4.A schematic design and calculation of the process of interaction of a water jet and ice particles with coating

An equation of an ice particle motion in the material prepared to be removed may be written in the following form:

$$m(t)\frac{dV}{dt} =$$

$$= \frac{1}{2}C_x\rho_C(T)S(h)V^2(t) - \sigma_{conp}(t)S(h) - F_{mp}(t,\phi); \quad (1)$$

where $m(t)$is a current value of the mass of an ice particle, taking into considerationRPT on the contact surface; $V(t)$ is a current value of the speed of penetration; $C_x$is a drag coefficient of an ice particle; $S(h,\varphi)$is a current value of a projection of section area of an ice particle, taking into account depth of penetration and presence of RPT on the elementary area within the solid angle $\Delta\varphi$:

$$S(h,\phi) = \pi R^2(t,\phi)\cdot\left[\frac{h(t)}{R(t,\phi)}H(R-h) + H(h-R)\right] \quad (2)$$

where$h(t)$, $R(t)$are the functions of depth of penetration and the current radius of an ice particle, taking into consideration RPT respectively; $H(...)$ isthe Heaviside step function.

The first component of the right part of an expression (1) characterizes the loss of kinetic energy of an ice particle, when interacting with the material. The second component reflects the resistance of material to destructive impact, and the third component is the friction force, influencing the particle, while penetrating into the removable material.

Friction force will depend on availability of liquid phase, which is relevant to the scheme of motion of an ice particle in the material with phase transitions on the contact surface:

$$F_{mp}(t,\phi) =$$

$$= f_V(t)\sigma_r(t,\phi)S(h,\phi)\cdot H\left[dA(t,\phi) - (q + C_V\Delta T_1)dm(t,\phi)\right] +$$

$$+2\mu_1\frac{V(t,\phi)}{\gamma(t,\phi)}S(h,\phi)\cdot H\left[(q + C_V\Delta T_1)dm(t,\phi) + dA(t,\phi)\right];$$

(3)

$$\sigma_x(t,\phi) = \frac{1}{2}\rho_C(t)V^2(t,\phi);$$

$$\sigma_r(t,\phi) = \frac{\upsilon_л}{1-\upsilon_л}\sigma_x(t,\phi); \quad (4)$$

where $(q + C_V\Delta T_1)dm(t,\varphi)$ isa value of the energy necessary for the transformation of the solid phase of the spherical layer by the mass dm in liquid state; $\mu_1$isa dynamic viscosity coefficient of liquid phase; γ is a size of a gap between ice particle surface and a profile of a cavity in an obstacle. The value of γ in bounds of a discrete angular coordinate $\Delta\varphi$is defined by the mass of the solid phase, limited by the surface in the form of a spherical layer, 'lost' in each particular discrete moment of time. $f_V(T)$ is a function of a speed coefficient of friction; $\sigma_x(t,\varphi)$ is a value of an axial tension on the contact surface of an ice particle with an obstacle, generally equal to a pressure of a velocity (dynamic, kinetic-energy) head; $\sigma_r(t,\varphi)$ is a value of radial voltage on the contact surface of an ice particle with an obstacle.

The work of the resistance forces, determining the intensity of the heat of the contact area, is represented with a help of the following sum:

$$A(t,\varphi)= A_1(t,\varphi)+ A_2(t,\varphi)+ A_3(t,\varphi), \quad (5)$$

where $A_1(t,\varphi)$, $A_2(t,\varphi)$, $A_3(t,\varphi)$is a work of inertial constituent of force of resistance, work of a friction force and work of forces of plastic resistance to the deformation of coating respectively.

Change of the size of an ice particle, when cleaning within an angular coordinate φ, is given according to the following dependency:

 DOI: 10.1051/matecconf/201712901014

$$d(t,\phi) = 2 \cdot \sqrt[3]{\frac{3}{4\pi\rho_Л}\left(m(t) - \int_0^{\frac{\pi}{2}} m_Л(\phi)d\phi\right)}; \quad (6)$$

where$\rho_л$ is a density of an ice particle; $m_л(\varphi)$ is a mass of an ice particle, «lost»,

$$A(t,\varphi)=Q(t,\varphi) \quad (7)$$

where$Q(t,\varphi)$ is a the thermal energy of the system of the contact of bodies.

In accordance with the condition of heat transfer through boundary surface of two bodies in contact in case of an ideal thermal contact [4] and the law of conservation of energy, an amount of ice, having been transmitted into an ice particle, and a respective change of its mass may be determined in a following way:

$$dQ_1(t,\phi) = \frac{\upsilon_M}{\upsilon_Л} dA(t,\phi);$$
$$m(t) = m(t-\tau) - \int_0^{\phi_K} \frac{Q_1(t,\phi)}{q + C_V^M \Delta T_1} d\phi, \quad (8)$$

where$\Delta T_1$is a range of temperature change of the contact layer of an ice particle, determining the RPT moment, $(\Delta T_1 = T_{OФП} - T_{01}$; $T_{OФП}$ is a temperature of RPT; T_{01} is an initial temperature of an ice particle; $m_0$is an initial mass of an ice particle.

Taking into consideration the fact that a (described in this paper) single act of an interaction of an ice particle with the material of coating, suffering damage, is similar to others, given a particular similarity coefficient, it becomes possible to calculate the percentage of energy, spent on heating of an ice particle, which is accompanied by appearance of local areas of a reverse phase tranfer (transmission) (RPT) of ice and on heating of the material.

4 Conclusion

A received thermo-physical model allows to develop and, having been proved scientifically, to appoint the modes of water-ice cleaning:
- water jet pressure;
- a diameter of a jet forming nozzle;
- the dimensions of ice particles;
- the temperature of storage of ice pellets;
- the distance from the nozzle to the surface;
- feeding speed of a nozzle apparatus during processing.

References

1. M.C. Kurco, R.F. Chadwick, Technika (Suisse), **vol. 21, no 3,** 2079 - 2083(1972)
2. B-L Liu, L-H Liu. Papers presented at the 14th Internationals on Jetting Technology. Held in Brugge, Belgium, 21-23 September, 203-210
3. M. Hashish, C.M. Dunsky, Papers presented at the 14th Internationals on Jetting Technology. Held in Brugge, Belgium, 21-23 September, 329-343
4. H. Kiyohashi, K. Handa. Proceedings of the International Symposium on New Applications of Waterjet Technology, Ishinomaki, Japan, 51-60 (1999)
5. H. Liu, T. Butler. Processing of the new applications of water jet technology. Isinomaki, Japan, 51 – 60 (1999)
6. *Water jet cutting: a production tool.* Machining and Production Engeneering.,**vol. 141, no 3631.** 18-19 (1983)
7. D.E. Hegland, Automation, **vol 22, no 8,** 40 – 44 (1975)
8. K.F. Hensen, E.C. La-Brush, Trans. ASME, **B. 97, no 3,** 1067 – 1073 (1975)
9. Vatteroch polymer-nyttskarwertyg. *Nord Emball,* **vol 41, no 2,** 25-26 (1975)
10. A.Y. Pushkarev, K.A. Golovin, A.B. Zabin, Y.I. Yeruhimivich, Proceeding of the International Symposium on New Applications of Water Jet Technology. Oktober 19-21, Ishinomaki, Japan. Ishinomaki Senshu Universiti, 421-425 (1999)
11. T.J. Louis, 5th American Waterjet Conference, Toronto, Canada, August, 145 – 168 (1989)
12. M. Hessling, 9th International Symposium on Jet CuttingTechnology, Sendai, Japan, October, **paper G3**, 357 - 376 (1988)
13. A.A. El-Domiaty, M.A. Shabara, A.A. Abdel-Rahman, A.K. Al-Sabeeh, Int. J. Adv. Manuf. Technol, **vol12, no 4,** 255-265. (1996)
14. P. Etchells. Aerosp. Compos, and Mater, **vol 3, no 1,** 40 – 43 (1991)
15. P.D. Kovscek, C.D. Taylor, E.D. Thimons, Rept. Invest / BurMines US Dep. Inter., **no 9201,** 1-10 (1988)
16. C. Merchant Howard, D. Chalupuik James, Noise Countr. Eng. J., **vol 29, no 3,** 85-89 (1987)
17. Anon, High Pressure Water Jet Systems, **Part 2, no. 4,** 20 –23 (1993)
18. Yazici, Sina Abrasive Jet Cutting and Drilling Rock, Ph.D. Dissertation in Mining Engineering, University of Missouri - Rolla, Rolla, Missouri, 203 p. (1989)
19. K. Faber, H. Oweinah, 10th International Symposium on Jet Cutting Technology, Amsterdam, **25,** 365 - 384(1990)
20. E.J. Chalmers, 6th American Water Jet Conference, Houston, Texas, 345 - 354(1991)