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Using of Hydrogen Sorbtion Storing Technology Based on Metal Hydrides for Cooling of High-Power Electric Generators with Steam Turbines

UMERENKOVA Ksenia[1,a], KONDRATENKO Olexandr[1,b]*, KOLOSKOVA Hanna[2,c], LYTVYNENKO Olha[1,d] and BORYSENKO Vitalii[1,e]

[1]National University of Civil Defense of Ukraine of SES of Ukraine, 94, Chernishevska str., Kharkiv, Ukraine, 61023

[2]N.E. Zhukovsky National Aerospace University «Kharkiv Aviation Institute» of MES of Ukraine, 17, Chkalov str., Kharkiv, Ukraine, 61070

[a]umerenkova@nuczu.edu.ua, [b]kondratenko@nuczu.edu.ua, [c]g.koloskova@khai.edu, [d]lytvynenko@nuczu.edu.ua, [e]borisenko@nuczu.edu.ua

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Abstract. The article analyzes the cooling systems that have become stuck during the operation of high-power electric machines, the importance of using water-cooling systems for them has been dubbed. The main part of the research is devoted to the consideration of nutritional and detailed methods of rational cooling of turbogenerators based on the use of innovative environment protection technologies, namely metal hydride hydrogen storage technologies as an environmentally friendly alternative to motor fuel. It is shown that an alternative to the traditionally used devices for cooling of electric machines with hydrogen is the use of hydrides of intermetallic compounds to implement the working processes of thermosorption compressors, which is due to the ability of reversible hydrides of intermetallic compounds to repeatedly sorb and desorb hydrogen at significantly different pressures, the value of which is determined by the temperature potential of the thermal effect, i.e. thermochemical compression of hydrogen. The methods of calculating the parameters used in the designing such devices have been analyzed, and the method of determining the parameters of phase equilibria of hydrides of intermetallic compounds has been suggested. Mathematical modeling of hydrogen sorption by intermetallic compounds, performed on the basis of the mathematical apparatus of the thermodynamic perturbation theory improved in the study and on the example of the intermetallic hydride $LaNi_5$, based on the application of the lattice gas model for metal hydrides. At the same time, due to the presence of an unchanged crystal structure of the metal, an increase in the volume of the crystal lattice in the process of hydrogen sorption was taken into account, which leads to the appearance of additional components in the potential energy, and the interaction between absorbed hydrogen atoms has also been taken into account. The calculated temperature dependences of the pressure on the plateau of the hydrogen solubility isotherm are in good agreement with the experimental data available in the literature. The operation of the metal hydride cooling system of TG excludes the occurrence of fire and explosive situations, and it also significantly increases the level of ecological safety indicators.

Introduction

The technologies for the production, storage, transportation and use of hydrogen as a motor fuel in power plants (PP) with internal combustion engines (ICE), in particular reciprocating engines for motor vehicles, are extremely relevant on a global scale [1, 2], although at the same time they are extremely science-intensive and require a wide body of research to ensure their effectiveness, fire-explosive, technogenic and ecologicaly safety [3, 4].

The relevance of the study also lies in the fact that the development of hydrogen energy in all its aspects for the needs of the Departments of the State Emergency Service of Ukraine (SES of Ukraine), in particular powering units of fire and emergency rescue vehicles (FERV), will allow to ensure eco-safety, energy efficiency and energy autonomy of their exploitation both during the times of armed aggression and in the process of post-war reconstruction of the economics and infrastructure of our country.

A separate issue in the application of hydrogen technologies is the storage of produced hydrogen as a motor fuel, especially for mobile PP, among which the most promising are adsorption technologies based on metallohydrogenides (MH) [5]. Some of the results of previous research on this topic by the authors of this study are protected by the relevant Patent of Ukraine for an invention [6].

In the theory of ecological safety (ES), one of the equal formulations of the concept of «environmental pollution» is a violation of indicators of the optimal state of the living environment. When considering the pollution of environmental components in more detail [7, 8], a distinction is made between natural pollution caused by volcanic eruptions, earthquakes, dust storms, mudflows, etc. – i.e., mainly catastrophic causes, and also caused by human activity – i.e., anthropological pollution [9,10]. The efficiency of human economic activity is generally still quite low, in particular, 98 % of natural substances go to waste and only about 2 % constitute a useful social product. And here it is important that metal hydride technologies (MHT) and hydrogen energy are characterized by extremely high efficiency indicators against this background [5].

Protection of all components of the environment – atmospheric air, water resources and soil from pollution by pollutants of various nature and origin is one of the main tasks of preserving the values of integral indicators of ecological quality of the environment [11] at a level that will allow comfortable existence as for the present [12, 13], as well as future generations of people [14], for example, a synergistic combination of such innovative technologies as the use of biofuel to power reciprocating ICE of hybrid cars [15] or particulate matter filters [16].

At the same time, the development and implementation of ecological safety technologies, primarily MHT and hydrogen energy [5] together with products from the disposal of waste of various combustible substances [17] and solid products of coal and fuel oil combustion [18], according to the majority of scientists, is a vital necessity of humanity, that is, it has a global character [8].

The main causes of anthropogenic pollution of environmental components in industrially highly developed countries of the world are the fuel and energy complex, industry – mainly powerful stationary sources, and transport – mainly numerous moving sources [11]. In addition, reciprocating ICE used in motor vehicles and FERV are the main pollutants of the atmosphere of cities with carcinogenic and mutagenic components. These substances can cause changes in hereditary properties in the human body [12], disrupting the genetic programs of cells [16, 19].

Problem Formulation

When designing and calculating the new models of electric machines (EM) of high power, the developers always face the need to solve the complex problem of ensuring design optimization according to antagonistic factors – forcing (increasing power and electromagnetic loads) while simultaneously reducing mass and dimensional indicators. In high-power synchronous EM, for example, in turbogenerators, its individual parts are subjected to significant mechanical and electromagnetic loads. As a result, a large amount of thermal energy is released in them, which necessarily leads to the need to solve the problems of improving methods of rational cooling [20]. At the same time, the rationality of the chosen cooling method should consist in taking into account the need to ensure a certain level of technical and ecological safety indicators of both the exploitation of the electric machine itself and the complex of technical means which that machine contains [21, 22].

The main purpose of the EM cooling system is to create conditions for heat exchange with the cooling medium, in which the temperature and excess of the temperature of the active elements of the machine above the temperature of the cooling medium are absorbed for reasons of compliance with the permissible limits based on the results of measurements [20], calculations, modeling or reference data [21, 22].

There are two ways of cooling electric machines: natural and artificial. All electric generators are designed and manufactured with artificial cooling, in particular air, indirect hydrogen, direct hydrogen. The method of cooling EM is determined by the value of their power [20]. Increasing the power of the generator unit requires an increase in electromagnetic loads, in which air as a cooling medium cannot ensure the removal of thermal energy in the required amount. Therefore, in the cooling systems of large turbine generators, the air is replaced by hydrogen [5].

So, based on the results of the analysis of literary sources, it is possible to formulate the following problem, to the solution of which our study is devoted, the results of which are presented in this article – the most important problem in electrical engineering when creating electric machines is the solution of the tasks of increasing power and electromagnetic loads while simultaneously reducing mass and dimensions, while necessarily there is a problem of removing a significant amount of thermal energy, which is a factor in the technical and economic perfection of the EM design and its working process, causes thermal stress on the materials of EM parts, and is a factor in energy pollution of environmental components. To ensure the reliable and efficient exploitation of such PP, it is necessary to maintain the values of permissible temperatures of active elements of structures within the recommended limits, which is carried out by cooling systems.

The purpose of the study is to provide a physical and mathematical justification for the use of hydrogen and sorbtion MHT of its storage in the cooling systems of powerful electric generators to increase technical and economic characteristics and technogenic and ecological safety indicators.

The object of the study is cooling systems of powerful electric generators.

The subject of the study is use of hydrogen and sorbtion MHT of its storage in cooling systems of powerful electric generators.

Analysis of Publications

Modern technologies for storing hydrogen produced for various needs are mostly based on solid-state storage devices of the adsorption type, where the porous adsorbent in the middle of pressure reservoitrs (cylinders) is MH of various nomenclature [23, 24]. The capacity of such adsorbents depends on the actual type of MH filler, its porosity, as well as the main thermodynamic parameters of the state – temperature and pressure, and hydrogen itself is a product of water electrolysis [25]. At the same time, alternative to MHT [26] types of hydrogen storage technologies are those containing porous carbon obtained from biomass [27], electrochemical technologies with carbon nitride electrodes and fuel cells with polymer electrolyte membranes [28] and other innovative materials [29, 30], including those based on graphene [31], lithium [32], nano-sized porous structures made of silicon [33], with a catalytic effect [34]. In general, the storage capacity of MH elements depends on many factors [35, 36] and is actively studied [37, 38].

To store large quantities of hydrogen, for example, in the PRC, natural reservoirs – caves are used [39, 40], metal-organic porous materials [41] or hydrogen is liquefied in cryogenic installations [42], but MHT is also considered as the basis for such solutions [43], although aspects of technogenic and ecological safety for non-standard situations during the exploitation of the corresponding equipment are also investigated [44].

Usually, the process of hydrogen adsorption in such installations is reversible and the release of stored hydrogen for consumer needs occurs through desorption, which in this case is an endothermic process, i.e., occurs with the absorption of thermal energy [45].

On the basis of a complex system that includes a source of hydrogen production with electricity consumption (for example, an electrolysis plant), means of its storage (for example, an adsorber based on MH) and a hydrogen consumer that is a source of electricity (for example, a gas turbine or reciprocating ICE or a steam boiler together with a steam turbine, which work on an electric generator) it is possible to build an effective system of recuperation of excess electricity during daily and seasonal fluctuations in the consumption schedule of powerful PP (nuclear or thermal)

[46]. The hydrogen released from the storage device can also feed power generating elements based on fuel cells [47].

Presentation of the Main Material of the Study

During the operation of the synchronous generator, the insulation of the stator and rotor windings is the most sensitive to temperature increase, therefore the windings first of all need to be cooled [5, 20].

With indirect cooling of the electric machine, all the cooling hydrogen is inside the generator body and does not directly come into contact with the conductors of the stator and rotor windings, and the heat released by them is transferred to the gas through a significant thermal barrier – the insulation of the windings.

With direct internal cooling, hydrogen is supplied internally to the cavities of the hollow conductors of the winding.

In turbogenerators with a capacity of more than 60 MW, direct internal cooling of the wires of the stator windings, rotor, and stator core with high-pressure hydrogen is used [5, 20].

The use of hydrogen cooling of large EM compared to air cooling has a number of advantages, which is explained by the special properties of hydrogen [5]. Hydrogen is 14 times less dense than air, which reduces power losses due to friction of the rotor against hydrogen. When the pressure increases, the thermal conductivity of hydrogen remains unchanged, and the heat transfer from the surface increases, due to which the excess of the surface temperature decreases. This makes it possible to increase the temperature rise in the insulation and in steel parts and, with unchanged weight and size indicators, to increase the power of turbogenerators by 15...20 %, that is, to increase EM power [5].

When exploiteting EM, an important issue is ensuring fire and explosion safety. Along with the advantages, hydrogen cooling creates a number of difficulties. A mixture of hydrogen with air can form an explosive, rattling mixture (hydrogen with its content in air from 4 to 74 % by volume). Therefore, to ensure the explosion safety of the EM, the turbogenerator body must be airtight and the hydrogen in it must be under excess pressure, which prevents air from entering the EM. The hydrogen content in the case is maintained at approximately 97 %. [5].

Under the influence of thermal influences, insulating materials deteriorate their properties and undergo aging over time, as a result, thermal and electrical breakdown of the insulation becomes possible. With hydrogen cooling, the service life of the insulation of the windings increases, since due to the absence of oxygen, which has an oxidizing effect, the destructive effect on the insulation of the windings of the machine is reduced. This reduces the risk of fire in the event of a short circuit inside the EM. In addition, the advantages of hydrogen as a heat carrier of the EM cooling system include the fact that it does not support combustion in the absence of oxygen [5].

Metal Hydride Systems of Energy-Technological Processing and Storing of Hydrogen

The property of a number of metals to reabsorb significant amounts of hydrogen initiated a number of technical ideas for the practical use of this phenomenon.

The reason for this is the unique combination of properties of the «metal–hydrogen» systems, including the possibility of achieving extremely high-volume concentrations of hydrogen atoms in the metal matrix, a wide range of operating pressures and temperatures, selectivity of hydrogen absorption-emission processes [48]. The use of MH as reversible hydrogen sorbents opens up prospects for the creation of new multifunctional heat-using devices for energy and technological purposes. Such devices make it possible to perform operations of receiving hydrogen, its long-term safe storage, purification from gas impurities, compression, delivery to the consumer with a given range of working pressures, working temperatures and mass flow rate.

On the basis of thermodynamic analysis of working processes of thermochemical compression of hydrogen using MH in the departments of Piston Power Plants and Hydrogen Energy Engineering of the A.M. Pidgorny Institute of Mechanical Engineering Problems of National Academy of

Sciences of Ukraine (IPMash of NAS of Ukraine) together with employees of the departments of Fundamental Disciplines of the Faculty of Technogenic and Ecological Safety of the National University of Civil Defense of Ukraine of State Emergency Service of Ukraine (NUCD of Ukraine) developed and created a number of MH systems and devices of various purposes for energy-technological hydrogen processing. The analysis of their applicability to ensure a certain level of technogenic and ecological safety indicators was performed in cooperation with scientific and pedagogical staff of the Department of Applied Mechanics and Environmental Protection Technologies of Faculty of Technogenic and Ecological Safety of NUCD of Ukraine. These MHT are used in various areas where hydrogen is used as a working fluid, including in general mechanical engineering, energy and transport.

Hydrogen accumulators developed at IPMash of NAS of Ukraine MH provide compact, explosion-proof and fire-proof storage of hydrogen for an unlimited time, with its further purification and release under a given increased pressure [49]. The use of such devices in the cooling systems of EM greatly simplifies the cooling schemes. This is achieved by the possibility of excluding gas cylinders, compressors, purification columns, pressure regulators from the system, which reduces the risk of an explosive situation. The devices have a wide range of stored hydrogen volumes and operating pressures.

The work considers an innovative scheme of MHT cooling of powerfull electric generator with steam turbine [6].

The device for hydrogen cooling of the EM of turbogenerator includes two identical sorber generators filled with a reversible hydride-forming substance, for example, an intermetallic compound $LaNi_5N_x$. Substances used as adsorbents of generator-sorbers are capable of reversibly and selectively absorbing hydrogen from the gas mixture during cooling and releasing it when heated under the required high pressure with a purity of not less than 99.9 % by volume. Each of the sorber generators is equipped with a heater and a cooler.

The sorber generators of the thermosorption compressor at the entrance are connected by lines that remove and supply hydrogen. The installation contains a control unit for switching the sorber generators to cycles of absorption or release of hydrogen, which alternately cyclically absorb and release hydrogen, that is, at each moment one of sobers works for absorption, and the other one – for release of hydrogen.

The selection of hydride-forming substances for sorber generators is based on the fact that the absorption of low-pressure hydrogen should occur with sufficient sorption dynamics, and the decomposition of the metal hydride should ensure the achievement of pressures at moderately elevated temperatures. Intermetallic compound $LaNi_5$ was used as MH for sorbents of generator-sorbers. Moreover, the absorption of hydrogen occurs with the formation of the hydride of the intermetallic compound $LaNi_5N_x$, which is accompanied by the release of the heat of sorption, which is removed by a water cooler. The sorption process occurs at low pressure. At the same time, in another generator-sorber, hydrogen is released due to the decomposition of $LaNi_5N_x$ hydride, which is accompanied by the absorption of the heat of desorption supplied by the heater. The process of hydrogen desorption occurs at high pressure.

Gas impurities that are contained in the hydrogen coming from the EM cooling shell of the turbogenerator are not absorbed by the MH of intermetallic compounds contained in the sorber generators, and at the beginning of each cycle of desorption and hydrogen supply, they are removed from the system.

The pressure in the hydrogen supply line exceeds the pressure in the cooling jacket of the turbogenerator`s EM, which ensures the necessary forced circulation of hydrogen in the cooling system of the EM of turbogenerator.

The stability of the hydrogen output is determined by the accuracy of the regulation of the working pressures, which depend on the temperature of the metal hydride, in the injection and discharge nozzles. Therefore, the temperature of the MH is used as a controlling factor.

When designing fire- and explosion-proof MH cooling devices for the EM of turbine generator, it is necessary to determine the parameters of the phase diagrams of the «metal–hydrogen» systems

– the relationship between the sorption (desorption) pressure, composition and temperature of the MH (PCT–diagrams).

Lattice H-Gas Model for IMC Hydrides

Complex physical processes observed during hydrogen absorption by metals can be replaced by studying similar processes on a simplified model. For this, the study uses the method of mathematical modeling, which will allow forecasting the data necessary for the design of MH systems. The adequacy of the mathematical model is checked by comparing the existing experimental data with the calculated characteristics of the MH. The analysis of calculation methods [48] showed that the lattice gas model is often used to describe the phase equilibria of metal hydrides. This considers the ideal rooting solution model. It does not take into account the increase in the volume of the crystal lattices of the metal when hydrogen is dissolved in them. Also, currently existing methods of modeling PCT ratios for specific hydride systems do not adequately take into account (H–H)–interactions.

A new approach [49,50] to the problem of calculating phase equilibria in «metal–hydrogen» systems consists in creating a mathematical model of phase transitions that takes into account the direct interaction between hydrogen atoms, as well as the indirect «deformation» contributions that arise in this case, that is, the potential energy due to expansion of the lattice during hydrogen dissolution.

The process of hydrogen sorption by metal can be divided into three stages.

At the first stage, adsorbed hydrogen in the metal lattice forms a disordered solid rooting solution (α-phase). The concentration of dissolved atoms depends on the pressure of hydrogen gas P and its temperature T.

At the second stage, additional regions of a solid disordered solution with a higher concentration of hydrogen (β-phase) appear.

The maximum concentration of hydrogen in MH is determined by the sorption capacity of the metal c_s. This parameter represents the number of internodal areas in the structure of the metal matrix, assigned to metal atoms, available for rooting of hydrogen.

The thermodynamic description of the properties of the hydrogen subsystem of the hydride and the H_2 molecular phase in equilibrium with it has been performed using a single method [51] – the modified scheme of perturbation theory (MTZ) which was described in [5] and used in previous researches [3,4]. In this case, within the framework of the model of the non-ideal (interacting) lattice gas of atomic hydrogen, the perturbation theory method allows us to adequately take into account the influence of the hydrogen-hydrogen attraction interaction.

In most intermetallic compounds, the initial crystal structure does not differ from the structure of the metal matrix in the hydride phases of IMC–hydrogen systems in the region of disordered α-, β-phases. In this case, the chemical potential $\mu_H = G_H / N_H$ of the hydrogen component of the IMC hydride (i.e., specific to a hydrogen atom, the Gibbs energy G_H) is described by the following formula:

$$\beta\mu_H^+(\theta,T) = \ln\frac{\theta}{1-\theta} + \frac{W_1\theta}{T(1+\alpha c_s\theta)} + \frac{W_2\theta^2}{T^2(1+\alpha c_s\theta)^2} \quad , \tag{1}$$

where $\beta = 1/(kT)$; $\mu_H^+ = \mu_H - \mu_H^{st}$; $\mu_H^{st}(T)$ – chemical potential in the standard state [49]; $\theta = C / C_s$ – the relative concentration of hydrogen, i.e., the degree of filling of the internodal regions available for rooting of H atoms; $C = n_{\mathrm{IMC}} \cdot c$ – hydrogen concentration in the form of the H/IMC ratio, i.e., on the formula units of IMC; n_{IMC} – the number of atoms in the formula unit; c – concentration of H in units of H/Me, i.e. per atom of the matrix; $\alpha = c^{-1}(\Delta V(c) / V)$ – the expansion coefficient of the IMC lattice upon hydrogen dissolution is defined as an increase in volume in relation to the volume V_0 of the «pure» matrix ($c = 0$). The values of C_s (sorption capacity of IMC) and c_s (maximum concentration of occupied internodal regions) are related by the relation·$c_s = C_s / n_{\mathrm{IMC}}$.

Constant values W_1 and W_2, which provide a connection between the macroscopic properties of IMC–hydrogen rooting solutions and the microscopic (atomic) characteristics of the hydrogen subsystem and the IMC metal matrix, are equal to:

$$W_1 = 2I_1 n_M (\sigma_1^3 / v_0) E_1 c_s, \quad W_2 = (3I_2 / 4I_1^2) W_1^2, \tag{2}$$

where $I_1 = -5.585$, $I_2 = 1.262$ – MTV parameters for H gas [51]; n_{M} – the number of matrix atoms in the unit cell; v_0 – the volume of the cell at $C = 0$; E_1 [in K] and σ_1 [in m] – parameters of the (H–H)-interaction potential $u_{\mathrm{H}}(r) = k\,E_1\,\varphi(r/\sigma_1)$.

Let us consider the phase equilibria in the hydrides of IMC $LaNi_5$ in the region of disordered α, β-phases. For the compound $LaNi_5$ with a hexagonal structure of the $CaCu_5$ type at the parameters $a_0 = 5.015\cdot10^{-10}$ m, $c_0 = 3.987\cdot10^{-10}$ m of the elementary lattice containing $n_{\mathrm{M}} = n_{\mathrm{IMC}} = 6$ atoms, its volume $v_0 = 86.84\cdot10^{-30}$ m^3. In the area of α–β-equilibrium, which is important from a practical point of view, the value $C_s = 6.7$ ($c_s = 1.12$). For the expansion coefficient, we have $\alpha \cong 2.9\cdot10^{-30}$ [m^3]$\cdot$ $n_{\mathrm{M}}/v_0 = 0.20$.

The combination $E_1\sigma_1^3$ in (2) describes the force constant of the (H–H)-interaction in the IMC lattice. According to estimates for $LaNi_5$, this value is 40–50 % of the skeletal interaction of free H-atoms in singlet states (model for Pd hydride [50]); we take $E_1\sigma_1^3 = 0.45\,(E_1\sigma_1^3)_{\mathrm{Pd}}$, which gives us $W_1 = -2.52\cdot10^3$ K, $W_2 = 1.93\cdot10^5$ K^2.

The curve of the decomposition of the homogeneous phase of the $LaNi_5$–H_2 system into α- та β-phases and the parameters of the critical point of the β→α–transition were determined: temperature $T_c = -0.216\,W_1 / (1 + \alpha c_s) = 445$ K, concentration $C_c = \theta_c \cdot C_s = 2.75$ H/$LaNi_5$ (where $\theta_c = 0.46 / (1 + 0.54\,\alpha\,c_s) = 0.41$), pressure H_2 $p_{H_2}^{(c)} = 104$ atm. These values (there are no experimental data on them) correspond much better to the type of phase diagram in this region of states than the values of $T_c = 450$ K, $C_c = 3.3$ H/$LaNi_5$ and $p_{H_2}^{(c)} \sim 200$ atm obtained in work [49] within the framework of a rough model – Bragg-Williams approximation for a rigid lattice ($C_c = 0.5\,C_s$).

The solubility isotherms of aone in $LaNi_5$ below and above the critical temperature T_s obtained on the basis of MTZ expressions [3,4] are shown in Fig. 1 in comparison with experimental data on desorption (signs). The temperature at calculated isotherms is indicated in °C.

The decomposition pressure of the β-phase, i.e., the pressure on the «plateau» of the β→α phase transition, can be represented by the Van't-Hoff equation [5,51]:

$$\ln p_{H_2}^{(PL)}(T) = -\frac{\Delta H_{\beta\to\alpha}}{RT} + \frac{\Delta S_{\beta\to\alpha}}{R}\ , \tag{3}$$

where for the enthalpy and entropy (β→α)–transition in the temperature range of 263 K ... T_c (445 K), the value = 29.43 kJ/mol H_2 = 104.6 J/(K·mol H_2) has been obtained. Calculated data on the decomposition pressure of the β-phase of $LaNi_5$ are compared in Fig. 2 with the data of experiments (signs) on hydrogen desorption, which were carried out in limited temperature intervals.

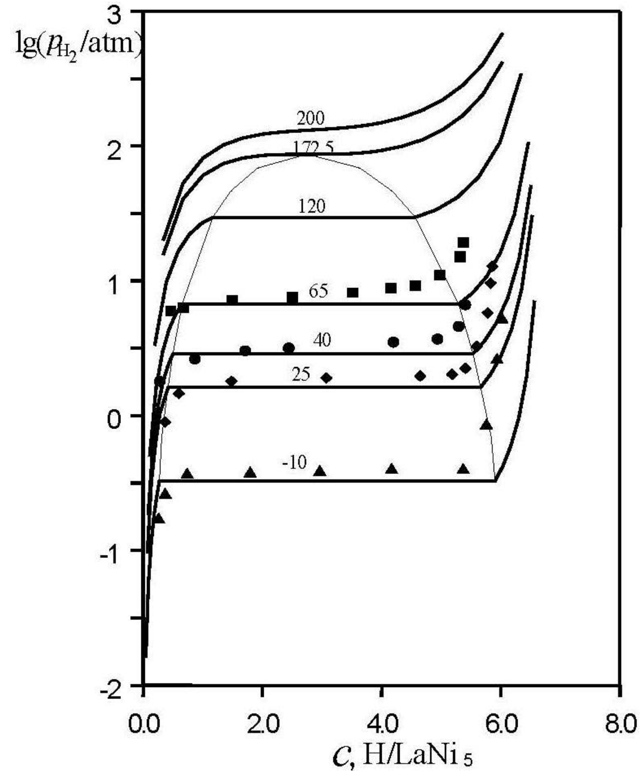

Fig. 1. Hydrogen solubility isotherms pH_2 (C) in the $LaNi_5$ compound at T < Tc and T ≥ Tc: temperatures at calculated isotherms are indicated in °C, the dotted curve is the calculated boundaries of one- and two-phase regions in the plane ($\log(pH_2)$ – C), symbols – experimental data on desorption [5,51]

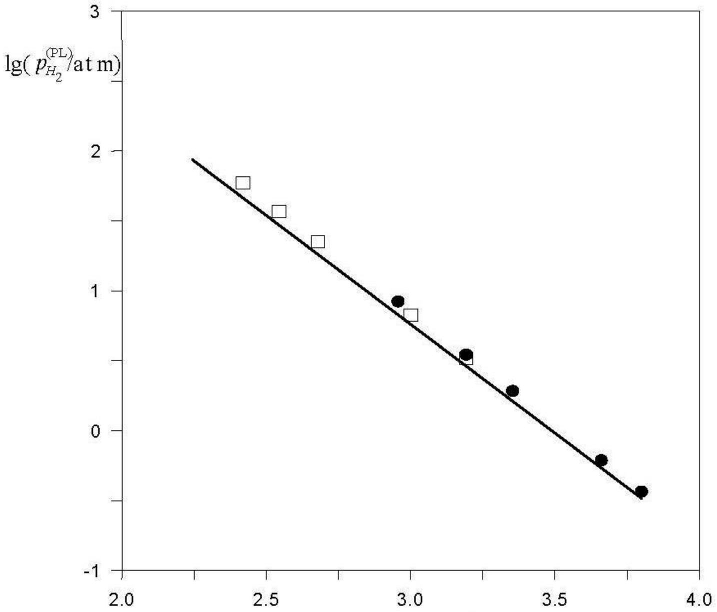

Fig. 2. Logarithm of the decomposition pressure of the β-phase of $LaNi_5$ hydrides as a function of inverse temperature: calculation according at $\Delta H_{\beta\to\alpha}$ = 29.8 kJ/mol H_2, $\Delta S_{\beta\to\alpha}$ = 104 J/(K·mol H_2); Symbols – experimental data on desorption in the $LaNi_5$ – H_2 system

Shown in Fig. 1 and 2 results allow us to conclude that the non-ideal lattice gas model for the hydrogen subsystem of IMC hydrides leads to the correct description of the main features of the PCT diagrams of the $LaNi_5$–H_2 system in the region of disordered phases in a wide range of pressures.

Conclusions

Thus, in the study, the results of which have been presented in this article, the scheme of hydrogen cooling of the electric generator of a high-power turbogenerator has been considered, in which sorption metal hydride hydrogen storage technologies have been used.

The implementation of the hydrogen cooling device of the electric generator according to the proposed scheme increases the efficiency of its operation due to the reduction of power losses due to forced circulation of hydrogen as a heat carrier from a mechanical hydrogen compressor, reduction of energy consumption for systematic regenerative heating of the sorbent in the hydrogen purification and storage system, exclusion of systematic purging of the system with pure hydrogen. Also, the value of the coefficient of friction decreases due to the increase in the degree of hydrogen purification. In addition, increasing the purity of hydrogen and its pressure leads to a reduction in the risk of electrical breakdown of the generator.

A methodology for calculating the parameters of phase equilibria, information about which is necessary for the design of MH cooling systems of an EM, is proposed. Mathematical modeling of phase equilibria in «hydrogen–metal hydride» systems was performed using a model of a non-ideal lattice gas of sorbed hydrogen atoms. The direct interaction between hydrogen atoms, the increase in the volume of the crystal lattice as a result of desorption has been considered, and the additional components arising in this case are taken into account in the potential energy of the interaction.

The pressures on the plateau of the solubility isotherm calculated in the $LaNi_5$–H_2 system are in good agreement with the available experimental data.

The scientific novelty of the results obtained in the research lies in the fact that the mathematical description of phase equilibria in the «hydrogen–metal hydride» systems for wide ranges of temperature and pressure changes has further been developed by applying the mathematical apparatus of the modified perturbation theory and discarding some simplifications.

The practical significance of the results obtained in the study is that the the improved mathematical apparatus for describing phase equilibria in «hydrogen–metal hydride» systems is suitable for designing sorption MH storage systems for hydrogen when it is used as a motor fuel for reciprocating and gas turbine ICE of PP, including units of fire and emergency rescue equipment, which will become useful both in the performance of official tasks in times of armed aggression and in the process of post-war reconstruction of the country's economics and infrastructure.

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