Power Engineering

This paper presents the obtained system characteristics of the package GPA-C-6,3A /56-1,45 using functional and functional-exergy approaches as well as design and experimental data on efficiency of centrifugal compressor (CC) and gas turbine (GT). When functional approach served the package efficiency was 25,8%, and when functional-exergy approach served it was 26,5%. At this in both cases there is a difference between the optimum condition of the package operation at which the max efficiency of the package is reached, and design condition of centrifugal compressor operation. The specified differences are determined by using impellers with blades exit angle 320 and vaned diffusers in centrifugal compressor stages. The analytical dependence to determine TCA fuel efficiency factor is presented. Coincidence of optimum of characteristics of the package exergy efficiency and fuel consumption factor of centrifugal compressor weight output is determined. In this case the package max exergy efficiency meets min value of the fuel consumption value. Using experimental data the design model verification for thermodynamic analysis of the operating process of the skid turbo-compressor package of linear compressor stations having single casing centrifugal compressor is performed. It is shown that mismatching of max values of the package efficiency by weight output for TCA system characteristics is 2,0% (relative one), that provides the required accuracy of the parameters when TCA designing.

Keywords: *package, compressor, exergy analysis, system characteristics, package exergy efficiency.*

С использованием функционального и функционально-эксергетического подходов, а также расчетных и экспериментальных данных об эффективности центробежного компрессора и газотурбинного двигателя получены системные характеристики агрегата ГПА-Ц-6,3А/56-1,45. Выполнена верификация расчетной модели для термодинамического анализа рабочего процесса блочно-комплектного турбокомпрессорного агрегата линейных компрессорных станций.

Ключевые слова: *агрегат, компрессор, эксергетический анализ, системная характеристика, эксергетический КПД агрегата.*

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Gerasimenko V. P., Shelkovsky M. Yu. Perspectives of development of gas-turbine engineering on the basis of achieved in aeronautical engine engineering (on the 100th anniversary of the birthday of V. N. Eershov)..12–14

Considerable contribution to the improvement of compressors of scientific schools, founded by academician G. F. Proskura and his pupil - honored worker of higher education of Ukraine, doctor of technical sciences, professor Vladimir Nikolaevich Ershov, is considered. It is shown that the speed factor is a rather convenient sign of type recognition and optimal shape of the impeller of the compressor, pump, fan, to ensure its maximum efficiency, necessary head and air flow.

Keywords: *compressor, efficiency, speed ratio, lengthening of blades.*

Рассмотрен весомый вклад в усовершенствование компрессоров научных школ, основанных академиком Г. Ф. Проскурой и его учеником - заслуженным работником высшего образования Украины, доктором технических наук профессором Владимиром Николаевичем Ершовым. Показано, что коэффициент быстроходности является достаточно удобным признаком распознавания типа и оптимальной формы рабочего колеса компрессора, насоса, вентилятора, для обеспечения его максимального КПД, необходимого напора и расхода воздуха.

Ключевые слова: *компрессор, КПД, коэффициент быстроходности, удлинение лопаток.*

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Aerohydrodynamics and Heat-mass Exchange

Matsevitiy Yu. M., Кostikov A. O., Safonov N. A., Ganchin V. V. To the solution of non-stationary nonlinear reverse problems of thermal conductivity..15–23

To solve the nonlinear boundary inverse heat conduction problem, two approaches are used with the regularizing method of A. N. Tikhonov, for which an effective algorithm for finding the regularizing parameter has been developed. The required functions with respect to the time coordinate are approximated by Schoenberg splines and the boundary inverse problem is reduced to the determination of the approximation coefficients. In the first approach, the temperature function is replaced by two terms of the Taylor series, depending on the approximation parameters. In this case, one must calculate the partial derivatives of the temperature function with respect to all the approximation parameters. Because of the very complicated dependence of the temperature function on the approximation parameters, the partial derivatives must be calculated using the finite difference method, which ultimately leads to the need to solve for each parameter an additional direct problem at each step of the iteration process. This leads to additional computational costs. The second approach uses the influence function method for the linearized mathematical model of the thermal process. This approach allows us to significantly reduce the time of the solution of the problem, but at the first steps of the iterative process it is necessary to take into account that the temperature field is still far from the true state and the nonlinear thermophysical characteristics that depend on this state are still far from the true values. In conclusion, it should be noted that the first approach is more universal, but for a large number of parameters leads to large computational costs. For the second approach, computational costs do not increase as much as for the first approach, but it can be used only *for solving boundary inverse heat conduction problems. From this it can be concluded that for the solution of multidimensional inverse problems these two approaches are desirable to be combined.*

Keywords: *inverse boundary-value heat conduction problem, heat flux, Tikhonov's regularization method, functional, stabilizer, regularization parameter, identification, approximation, Schoenberg splines.*

Для решения нелинейной граничной обратной задачи теплопроводности применяется метод регуляризации А. Н. Тихонова с эффективным алгоритмом поиска регуляризирующего параметра. Искомый тепловой поток на границе по временной координате аппроксимируется сплайнами Шёнберга. Применяется метод функций влияния, для чего нелинейная задача сводится к последовательности линейных обратных задач.

Ключевые слова: *обратная граничная задача теплопроводности, тепловой поток, метод регуляризации А. Н. Тихонова, функционал, стабилизатор, параметр регуляризации, идентификация, аппроксимация, сплайны Шёнберга.*

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Uspensky B. V., Avramov K. V., Nikonov O. Ya. Nonlinear normal modes of forced vibrations in piecewise linear systems under superharmonical resonances 24–30

The paper describes a new technique for analysis of forced oscillations in strongly nonlinear piecewise linear systems considering superharmonic resonances. Nonlinear oscillations of piecewise linear systems have complex behavior including bifurcations, chaotic oscillations, sub- and superharmonic responses. Extreme importance of piecewise linear systems analysis due to their abundance in machinery and, particularly, engines makes the problem of nonlinear oscillatory dynamics in such systems highly topical. Nonlinear normal modes as an approach for analysis of nonlinear oscillations were developed by Rosenberg. Shaw and Pierre amended this approach using an invariant manifolds ideology. This paper utilizes and modifies Shaw-Pierre nonlinear normal modes approach to analyze superharmonical oscillations occurring in piecewise linear mechanical systems under harmonic excitation. The Rauscher technique is used to bring a non-autonomous dynamical system to an equivalent pseudo-autonomous one. To commit analysis of superharmonic resonances in the system, a modification to the Rauscher method is proposed. Eventually, an analysis of a mechanical system modeling a circuit of a power transmission of an internal combustion engine is performed. Amplitude-frequency diagram is obtained for the second superharmonical resonance. It is discovered that in the configuration space the second superharmonical nonlinear normal mode contains delamination that prevents it to be found using Rosenberg nonlinear normal modes technique.

Keywords: *superharmonical resonances, Rauscher technique, nonlinear normal modes, configuration space.*

Предложен метод расчета вынужденных колебаний существенно нелинейных кусочно-линейных систем при супергармонических резонансах. В основе этого метода лежит сочетание нелинейных нормальных форм и метода Раушера, с помощью которого неавтономная динамическая система сводится к эквивалентной автономной. С помощью предложенного метода исследуются супергармонические колебания в участке силовой передачи двигателя внутреннего сгорания. Подробно рассматриваются свойства резонансных колебаний.

Ключевые слова: *супергармонические резонансы, метод Раушера, нелинейные нормальные формы, конфигурационное пространство.*

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Kalantarly N. M. Equistrong hole shape for crack growth deceleration under longitudinal shear...........31–37

The problem of finding an equistrong hole shape in crack tip and its effect on crack development is considered. A criterion and method for the problem solution to prevent brittle fracture of solid weakened by longitudinal shear crack is proposed. Using the perturbation method and the conformal mapping to parametric plane, the problem in each approximation is reduced to boundary value problem for analytic function. In each approximation, the solution of the boundary value problem for analytic function in the class of everywhere bounded functions (stresses) is obtained in closed form. The reduction of the stress concentration on the hole's contour in the crack tip is done by the method of least squares. To determine expansion coefficients of the Fourier series of the required hole shape function and the optimal value of circumferential tangential stress in surface layer of the hole an infinite linear system of algebraic equations is obtained for elastic material. The condition of brittle fracture is obtained.

Keywords*: crack, longitudinal shear, optimal hole, principle of equal strength.*

Рассмотрена задача об отыскании равнопрочной формы отверстия в кончике трещины и ее влияния на развитие трещины. Предложен критерий и метод решения задачи по предотвращению хрупкого разрушения тела, ослабленного трещиной продольного сдвига.. Получено условие хрупкого разрушения

Ключевые слова: *трещина, продольный сдвиг, оптимальное отверстие, принцип равнопрочности.*

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Steady-state harmonic oscillations of an elastic layer weakened by two through openings with pulsing normal pressure acting at their surfaces are under consideration. The integral representations of unknown functions based on the theory of homogeneous solutions with application of MacDonald special functions are in use. These representations allow us to satisfy automatically the boundary conditions on the surfaces of openings. The boundary problem is reduced to the system of six integral equations for every harmonics. Its solution is obtained numerically. Some numerical examples are presented. The isotropic layers with elliptical cylindrical surfaces are considered. The examples demonstrate some important characteristic features of the tension distribution and its influence on frequencies depending on the distance between openings and value of Poisson's ratio. The effect of widening the first resonance base via Poisson's ratio decreasing is observed. The influence of two openings on each other is investigated.

Keywords*: harmonic oscillations, layer with two opening, integral equations.*

Решена задача гармонических упругих колебаний слоя с двумя сквозными отверстиями, на поверхности которых действует нормальное пульсирующее давление. Граничная задача сведена к системе интегральных уравнений, которая решается численно. Приведены примеры, где исследуются особенности распределения окружного напряжения по частоте в зависимости от расстояния между отверстиями и коэффициента Пуассона.

Ключевые слова: *гармонические колебания, слой с двумя отверстиями, интегральные уравнения.*

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This article presents an analytic-numerical solution of the first BASIC spatial problem of the theory of elasticity (on the boundary of a stressed one) for several parallel circular, cylindrical hollows in an elastic space. As an example, a numerical analysis of the stress-strain state of space with two empty spaces and the Mutual Influence of the voids are presented. For two parallel cylindrical cavities in a space a stressful state is found. Results are obtained with a single load of the first cylinder, separately when the load of the second cylinder. By changing the distance between the cylinders, the effect of distance on the tensile state of cylindrical cavities has been investigated. The method of solving the problem of elasticity theory is proposed, when the stresses are given on the boundaries of several parallel cylinder circular cavities. Numerical studies of an algebraic system for two cylinders make it possible to assert that its solution can be with any degree of accuracy found by the method of reduction. The graphs given give an idea of the peculiarities of the distribution of displacement and stress in the body in the most interesting area adjacent to the cavities, and on the mutual influence of cylinder cavities.

Keywords: *cylindrical cavities in space, Lame's equation, generalized Fourier method.*

Приведено решение трехмерной задачи теории упругости, когда на границах параллельных цилиндрических полостей в упругом пространстве заданы напряжения. Решение системы уравнений Ламе получено обобщенным методом Фурье в цилиндрических координатах, связанных с цилиндрами. Бесконечные системы линейных алгебраических уравнений, к которым сведена проблема, решаются методом усечения. В результате были найдены перемещения и напряжения в упругом теле. Числовые результаты приведены для случая двух цилиндров.

Ключевые слова: *цилиндрические полости в пространстве, уравнения Ламе, обобщенный метод Фурье.*

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The physics of the processes of an eddy current electromagnetic sensor of a flaw detector in cooperation with the controlled sample in the Ш-shaped core is revealed and described. The cases of absence of a defect (a crack or a void) and the presence of one or several defects are considered. The formulas for determining the parameters of the flaw detector are derived. In particular, the dependence of the pulling force, in the case of the ferromagnetic material under investigation, on the frequency of the generated signals. This tractive force occurs between the sensor core of the flaw detector and the controlled sample and makes it difficult for the sensor to advance along the material when searching for cracks. It is shown that the higher the frequency, the less the tractive effort. In addition, from the formula of the electromotive force of induction for both output signals of the measuring windings and for eddy currents, an increase in frequency provides an increase in these electromotive forces, thereby increasing the sensitivity of the sensor.

Keywords*: defect, eddy current, sensor of the flaw detector.*

Представлены результаты исследования электромагнитного вихретокового датчика дефектоскопа с Ш-образным сердечником, выявлены процессы, возникающие в сердечнике и контролируемом материале. Рассмотрены варианты без трещины в контролируемом материале, с трещиной и с несколькими трещинами, выведены формулы для определения параметров датчиков.

Ключевые слова: *дефект, вихревой ток, датчик дефектоскопа.*

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Applied Mathematics

Maksymenko-Sheiko K. V., Litvinova Yu. S., Sheiko T. I., Khazhmuradov M. A. Mathematical modeling of heat exchanger with liquid flow for tube with polyzone finning 58–63

The finning of heat-transmitting surfaces is widely used in technics for heat-exchange surface increasing. The finning forms are rather various. The finning not only increases a heat-exchange surface, but also renders the big influence at stream hydrodynamics, and thus at heat-emission factor. The more favourable finning forms (so-called polyzonal and herring-bone) have been developed during experiments with various finning methods of fuel element claddings. The lacks of herring-bone surfaces are the high labour input and the cost price of manufacturing. These lacks can be removed due to the 3D-printing technology, since the advantages of 3D-printers using are the decrease of the cost price of production manufacturing, the reduction of its occurrence terms at the market, the modeling of objects of any form and complexity, the speed and high accuracy of manufacturing, the possibility of use of the various materials maintaining high temperature, intensive mechanical loadings and influence of harmful chemical substances. It is necessary to create the computer 3D-model of desirable object during preparation for 3D-printing. The analysis of classical representations has shown that their practical application is limited or demands significant efforts for construction of models of complex geometrical objects. One of the most perspective is the functional representation based at the using of implicit mathematical functions language with constructive tools of the R-functions theory developed by academician V.L. Rvachev. The developed techniques of construction of the equations of various finning surfaces at the R-functions theory basis and their subsequent 3D-realization are shown. The research of hydrodynamical and temperature fields at polyzonal finning of fuel element cladding are resulted. The consecutive construction of the longitudinal, polyzonal and herring-bone finnings equations of the fuel element claddings allows to track the algorithm complication process due to corresponding superpositions in the initial equation which kind does not change. It is one of examples of advantage of the geometrical objects' analytical identification realized with the R-functions help. The analytical description of the designed objects enables to use symbolic geometrical parameters, complicated superposition of functions consequently allowing to change the design elements of these objects. The results of the velocity and temperature fields research for various values of twisting parameter, testifying that the warming up in the intercostal zone increases with increase in value of twisting parameter, are shown.

***Keywords**: R-functions theory, Ritz method, heat transfer, fuel element cladding, polyzonal and herring-bone finning, 3D-printer.*

Приведены разработанные методики построения уравнений различных поверхностей оребрения на основе теории R-функций с их последующей реализацией на 3D-принтере и исследования гидродинамических и температурных полей при полизональном оребрении оболочки ТВЭЛа. В ходе экспериментов с различными методами оребрения оболочек ТВЭЛов были разработаны более выгодные формы оребрения, так называемые полизональное и шевронное, реализацию которых предлагается выполнять на 3D-принтере. С точки зрения универсальности одним из наиболее перспективных выглядит функциональное представление с конструктивными возможностями теории R-функций. Приведены результаты исследования поля скоростей и температурного поля для различных значений параметров закрутки и оребрения.

***Ключевые слова:** теория R-функций; метод Ритца; теплообмен; оболочка ТВЭЛа; полизональное оребрение.*

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Ecological Aspects of Operation of Power Equipment

The article substantiates the finding that the key component contributing to global crises on Earth, including current warming, is the economic (predatory and hyper-consumption) activity of the ever-increasing human population, including the significant growth in inefficient use of natural resources, as well as the extremely hazardous environmental pollution by supertoxicants. All this has led to suppression, degradation, destruction and annihilation of ecosphere systems, changes in the global flow of carbon and oxygen, reduction of carbon dioxide drain and accumulation of greenhouse gases in the troposphere and, as a consequence, to global warming. The technique of determining the reserves of energy and resources on the basis of the integral ion model of functioning of territorial-industrial complexes is considered in the article. The main aim of the work is to develop the methods of integration of energy and material flows enterprises located in territorial and industrial zones, providing rational use of all kinds of resources, reduction of waste and anthropogenic impact on the environment. One way to achieve this aim is a methodology hased on intersectoral integration energetic and technological industrial potential, which can be combined in the framework of territorial and industrial complexes. It is proposed a mathematical model for the analysis of reserves of energy and resources in the implementation of technological integration plants located within the territorial and industrial zones, as well as analysis of consumption of resources and waste generation of enterprises. The results can be applied to the fuel and energy complex, machine building enterprises, mining and metallurgical and chemical-technological profile. The proposed technique makes it possible to realize in practice low-waste energy efficiency production for the development of territorial and industrial complexes, provides a reduction in the unit cost of energy and raw materials in 2,2–3,5 times with simultaneous reduction in emissions by 2–3 Limes.

Keywords*: climate change, greenhouse gases, energy, fuel, ecology.*

Обосновывается вывод, что важнейшей составляющей глобальных климатических изменений на Земле, в том числе современного потепления является антропогенная деятельность, характеризующаяся неэффективным использованием природных ресурсов, а также – предельно опасным уровнем загрязнения окружающей среды. Показано корреляцию объемов выбросов парниковых газов техногенного происхождения с увеличением среднегодовой температуры.

Ключевые слова: *теория климатические изменения, парниковые газы, энергетика, топливо, экология.*

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