Aerohydrodynamics and Heat-mass Exchange

Gnesin V. I., Kolodyazhnaya L. V., Kravchenko I. F., Merkulov V. M., Scheremetyev A. V., Petrov A. V. The numerical analysis of aeroelastic behaviour of blade row of aviation engine fan...........3–11

There presented the numerical analysis of oscillating blade row aeroelastic behaviour of aviation engine fan. The numerical method is based on solution of coupled problem of unsteady aerodynamics and blades elastic oscillations, equations in which are integrated with parallel-sequential information exchange on each iteration. There presented the calculation results of aeroelastic characteristics and aerodamping coefficients of fan blade row under harmonic and coupled blades oscillations for given regimes of boundary conditions in inlet and outlet of blade row. There conducted the numerical analysis of the influence of the 1st natural form frequency on blades oscillations regimes with account of interaction of five natural forms. There shown that increase of the 1st natural form frequency quotes to increase of aerodynamical stability of blades oscillations.

Keywords: *fan, three-dimensional ideal flow, numerical modelling, unsteady loads, aeroelastic characteristics.*

Представлен численный анализ аэроупругого поведения вибрирующего лопаточного венца вентилятора авиационного двигателя. Численный метод основан на решении связанной задачи нестационарной аэродинамики и упругих колебаний лопаток, уравнения которых интегрируются параллельно-последовательно с обменом информацией на каждой итерации. Приведены результаты расчетов аэроупругих характеристик и коэффициентов аэродемпфирования лопаточного венца вентилятора при гармонических и связанных колебаниях лопаток для заданных режимов граничных условий на входе и выходе за венцом. Проведен численный анализ влияния частоты 1-й собственной формы на режим колебаний лопаток с учетом взаимодействия пяти собственных форм. Показано, что повышение частоты 1-й собственной формы приводит к повышению аэродинамической устойчивости колебаний лопаток.

Ключевые слова: *вентилятор, трехмерный идеальный поток, численное моделирование, нестационарные нагрузки, аэроупругие характеристики.*

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Rusanov R., Szymaniak M., Rusanov A., Lampart P. Development of the 500 kW and 1 MW ORC turbine flow parts 12–19

There paper presents two types of developed ORC turbines. The silica oil (MDM) is used as the working media. Proposed turbines are developed for electric power in 500 kW and 1 MW. For the designing of that turbines there were only one geometric constraint: the minimum height of the blade – 20 mm. The final 3D calculations of all turbine stages are provided with accounting the real properties of working media. Gasdynamic efficiency of the developed turbine flow parts is adequate for the such type of power machines.

Keywords: *ORC, flow part, analytical method of profiling, spatial flow, numerical modeling, modified Benedict-Webb-Rubin equation with 32 members.*

Рассмотрены несколько вариантов проточных частей осевых турбин мощностью 500 кВт и 1 МВт для когенерационной установки, использующей в качестве рабочего тела силиконовое масло (MDM). Единственным геометрическим ограничением для проектирования этих турбин было минимальная высота лопатки – 20 мм. Окончательные трехмерные расчеты всех ступеней турбины проведены с учетом реальных свойств рабочего тела на основе модифицированного уравнения состояния Бенедикта-Вебба-Рубина. Газодинамическая эффективность разработанных проточных частей турбин удовлетворяет требованиям, предъявляемым к энергетическим машинам подобного рода.

Ключевые слова: *изотропная ORC, проточная часть, аналитический метод профилирования, пространственное течение, численное моделирование, модифицированное уравнение состояния Бенедикта-Вебба-Рубина с 32 членами.*

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Modeling of the rotor thermal state of a synchronous turbogenerator of 550 MW with direct cooling of the winding by hydrogen is performed. The temperature field of the rotor is investigated by finite element method in a three-dimensional formulation. Mathematical modeling of the task is implemented in the SolidWorks computer environment. Correlations for determination of the heat transfer coefficients that were obtained by different scientists in 1959-1970 and applicated in the design of cooling systems for nuclear rocket engines are given. Correlation was selected that provides temperature distribution corresponds to test results. The temperature distribution of the rotor winding was obtained as a result of thermal test of 550 MW turbogenerator which were carried out at State Enterprise «Plant «Electrotyazhmash» in idling and short circuit mode. According to test results, maximum temperature of the rotor winding in the nominal mode was 74.7 ° C (347.7 K). The comparison of the *calculated data and test results shows that the difference is not more than 10%. The thermal state of the rotor does not restrict of the nominal power of the generator.*

Keywords: *turbogenerator, rotor winding, thermal state, finite element method.*

Выполнено моделирование теплового состояния ротора синхронного турбогенератора мощностью 550 МВт с непосредственным охлаждением обмотки водородом. Температурное поле ротора исследовано с помощью метода конечных элементов в трехмерной постановке. Математическое моделирование поставленной задачи реализовано в компьютерной среде SolidWorks. Приведены корреляции для определения коэффициентов теплоотдачи, которые были получены разными учеными в 1959-1970 гг. и нашли применение в области проектирования систем охлаждения ядерных ракетных двигателей. Выбрана корреляция, которая обеспечивает соответствие расчетного распределения температур в роторе и испытательного. Распределение температур в обмотке ротора получено в результате проведения тепловых испытаний турбогенератора мощностью 550 МВт на ГП «Завод «Электротяжмаш» в режиме холостого хода и короткого замыкания. По результатам испытаний максимальная температура обмотки ротора в номинальном режиме составила 74,7 °С (347,7 К). Сравнение расчётных данных и результатов испытаний показывает, что погрешность расхождения составляет не более 10%. Тепловое состояние ротора не накладывает ограничений на величину номинальной мощности генератора.

Ключевые слова: *турбогенератор, обмотка ротора, тепловое состояние, метод конечных элементов.*

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Dynamics and Strength of Machines

A nonlinear dynamical system with a finite number of degrees of freedom is obtained, which describes the forced oscillations of the shallow shell for its geometrically nonlinear deformation. To derive this dynamic system, the method of given forms. In the region of the first fundamental resonance, the Neumark-Sacker bifurcations are investigated. As a result of these bifurcations, almost periodic oscillations arise, which are transformed into chaotic oscillations. The properties of these oscillations are explored.

Keywords: *nonlinear periodic oscillations of a shallow shell, stability of oscillations, almost periodic oscillations, chaotic oscillations*

Получена нелинейная динамическая система с конечным числом степеней свободы, описывающая вынужденные колебания пологой оболочки при ее геометрически нелинейном деформировании. Для вывода этой динамической системы применяется метод заданных форм. В области первого основного резонанса исследованы бифуркации Неймарка-Сакера. В результате этих бифуркаций возникают почти периодические колебания, которые преобразуются в хаотические. Исследуются свойства этих колебаний.

Ключевые слова: *нелинейные периодические колебания пологой оболочки, устойчивость колебаний, почти периодические колебания, хаотические колебания.*

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Nonlinear behavior of a two-layer curved system is investigated. The system of layers is exposed distributed load on surface and disturbances force. The force is applied to the lower layer. At the boundary where the layers are separated, in the contact zone, boundary conditions corresponding to the clutch area slipping and separation are possible. The method of solution is based on the variation formulation of the boundary value problem using characteristic functions. For the solving of the problem the finite element approximation is used. Numerical analysis of non-linear stress-strain state and stability of the upper layer depending on the height of the bottom layer, the angle model, the coefficient of friction and the relative stiffness of the layers, was produced. Analysis of the behavior of a two-layer system showed that at a certain ratio of the thickness of the layers and the values of the existing load, the deformation in the presence of slip, contact, and separation zones is possible. Moreover, the existence of this behavior depends on the system parameters and can be found in series calculations with load change from zero to the final value. Possibility and characteristics the loss of stability of the layer and the entire system have been found, their relationship with parameters of the system are investigated.

Keywords: *contact problem, system's stability, layer's stability, layer's separation, friction.*

Изучено нелинейное поведение двухслойной криволинейной системы, нагруженной распределенной поверхностной нагрузкой и возмущением в виде силы, приложенной к нижнему слою. Задача формулируется в вариационной постановке. Произведен численный анализ нелинейного напряженно-деформированного состояния слоя в зависимости от высоты нижнего слоя, угла модели, коэффициента трения и относительной жесткости слоев. Установлены возможность и особенности потери устойчивости нижнего слоя и всей системы в целом, исследована их связь с параметрами системы.

Ключевые слова: *плоская контактная задача, устойчивость системы, устойчивость слоя, отрыв слоя, трение.*

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Applied Mathematics

Litvin O. M., Yarmosh E. V., Chorna T. I. Spline interfletation method in finding the largest (least) values for function of three variables in multiextreme tasks 40–48

The decision of many practical tasks in the sphere of economy, management, technique and engineer puts new and new tasks for the theory of optimization. An aim of optimization is finding the largest or the least value among potentially possible. This aim can be achieved by various methods. Among them - the methods of discrete, undifferentiated and stochastic optimization. Interpolation methods are more widely used now in the mathematical modeling of many industries and spheres of activity. Unfortunately, authors often use only individual points values of the investigated function in the construction of appropriate algorithms of optimization methods.
In this article for the solution of task of finding the largest and the least values of continuous function of three variables in the closed domain it is offered to use operators of spline interlineation on the system mutually perpendicular lines, built by means of operators of spline interflatation function of three variables. It is used method of reduction of general task to the sequence of tasks of finding the approximate largest or least value of function on the system mutually perpendicular lines. In this work theorems and their proofs are described. Theorems are about the spline- interfletation operator and its properties, spline-interlineation operator and its properties and error in the approximation of a function by spline-interlineation operator. An example of finding the least value of function of three variables is examined. Solution steps are described. Calculated data testify to efficiency of

the offered and investigated method of using spline-interlineation operators on the system mutually perpendicular lines built by means of spline-interflatation operators of three variables function. Authors intend to use the offered method to find the largest (the least) value of function of n variables.

Keywords: *operators of spline-interlineation, operators of spline-interfletation, tracks of function, system mutually perpendicular lines.*

В данной статье предлагается для решения задачи нахождения наибольшего и наименьшего значений непрерывной функции трех переменных в замкнутой области $D = [0, 1]^3$ *использовать операторы сплайн-интерлинации на системе взаимно перпендикулярных прямых, построенные с помощью операторов сплайн-интерфлетации функции трех переменных. Рассмотрен пример. Приведен анализ вычисляемого элемента.*

Ключевые слова: *операторы сплайн-интерлинации, операторы сплайн-интерфлетации, следы функции, система взаимно перпендикулярных прямых.*

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Non-traditional Energy Technologies

The purposes of accomplished work were the investigation, design, manufacturing and operational demonstration of PV-H2 SMART Grid energy complex and its constituent elements for transformation of the renewable forms of “dirty” energy (solar) into conventional (quality) electrical energy. Statics concentrator system is used to reduce the unevenness of solar energy input and improve the efficiency of the photoelectric module. The hydrogen as energy carrier and hydrogen fuel cells are possible option to store different amounts of energy for relatively long times with low losses.

Keywords: *static concentrator, energy storage, electrolysis technologies, photovoltaic module.*

Рассмотрены вопросы проектирования, исследования и эксплуатационной демонстрации фотоэлектрического-водородного комплекса сети электроснабжения и его составных элементов для преобразования неравномерно поступающей энергии возобновляемых источников (солнечной) в обычные (качественные). Стационарная концентрирующая система применяется для снижения неравномерности поступления солнечной энергии и повышения эффективности фотоэлектрического модуля. Водород в качестве энергоносителя и водородных топливных элементов является возможным вариантом для хранения различных количеств энергии в течение относительно долгого времени с низкими потерями.

Ключевые слова: *стационарный концентратор, хранение энергии, электролизер, фотоэлектрический модуль.*

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Ecological Aspects of Operation of Power Equipment

Many publications have shown that, with some degradation of a diesel engine's power and economic performance, using fuel compositions containing vegetable oil ethers significantly reduces the toxicity of engine exhaust gases. Our experimental research into the motor qualities of mixture fuel have shown that increasing the volume share of the biological component of binary fuel slowly degrades the energy indicators of a diesel engine and improves its ecological features. In so doing, engine exhaust gases toxicity is not reduced drastically. The main goal of the research effort was increasing the energy and ecological indicators of a biodiesel engine by improving the methods of its adaptation to biodiesel fuel compositions. The task of the investigation was a comprehensive experimental validation of such methods. A theoretically substantiated method of compensating for diesel effective power losses was suggested by changing to fuel mixture supply. The method consists in increasing the energy content of engine cylinders by increasing the maximum fuel injection rate. Experiments have proved that increasing biodiesel engine power does not degrade ecological indicators considerably. These indicators are better than similar ones of a diesel prototype as to the level of emission of exhaust gases (EG) for carbon oxide and carbon dioxide by 36% and 11%, respectively; for nitrogen oxides, by 18%; for unburned carbon, by 7 times, and for EG smoke opacity, by 28%. Analysis of publications and preliminary estimates and experiments have defined actions to be taken to reduce the content of nitrogen oxides and solid particles in the exhaust gases of a diesel engine running on mixture fuel. The actions are to shorten fuel injection advance and use lean fuel-and-air mixtures. Experiments have shown that optimising the fuel injection advance angle and the minimal value of the air ratio improves dramatically (up to 50-80%) the ecological performance of a biodiesel engine. The new methods of improving the energy and ecological indicators of a biodiesel engine have confirmed experimentally their high effectiveness. Besides, these methods have a regulating character, making their implementation easier and cheaper.

Keywords: *diesel engine, biodiesel fuel, effective power, effective efficiency, toxicity.*

Предложен теоретически обоснованный метод компенсирования потерь эффективной мощности дизеля вследствие перехода на питание бионефтяными топливными композициями. Экспериментально доказано, что увеличение мощности биодизельного двигателя до уровня базового дизеля сопровождается ухудшением экологических показателей, преимущества которых перед аналогичными показателями дизельного прототипа все-таки сохранятся. Проведена экспериментальная проверка определенных аналитически мероприятий по снижению содержания оксидов азота и твердых частиц в отработавших газах дизеля, работающего на смесевом бионефтяном топливе.

Ключевые слова: *дизельный двигатель, биодизельное топливо, эффективная мощность, эффективный КПД, токсичность.*

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High Technologies in Mechanical Engineering

When constructing mathematical models of corrosion wear of structures, it is also necessary to take into account the work of protective coatings and determine the duration of the incubation period characterizing the durability of the protective coatings used. Protective coatings are barrier layers that impede the penetration of an aggressive medium to the surface of the structure and push back the onset of the process of intense corrosion. When calculating structures with protective coatings subjected to corrosive wear, it is necessary to take into account the joint operation of both the structural element itself and the protective coating, which leads to stresses in protective coatings, a more intensive decrease in the protective properties of these coatings and, as a result, premature failure. This study is devoted to the development of a new mathematical model of the combined approach to the calculation of corrosion and protective properties of anticorrosive coatings. As the basic equation of corrosion, the Dolinsky model is used, which allows one to take into account the effect of stresses on the corrosion wear of structures. The implementation of this model is demonstrated by the example of optimizing the bent elements of a rectangular section. Analytical solutions were obtained in stages to determine the transverse dimensions and time of complete loss of the anticorrosive coating of these elements. As a result of optimization, optimal initial section sizes were found by the criterion of the minimum volume of the structure. The proposed model, as well as the considered approach to its implementation when optimizing structures working under corrosion conditions, can be used both in analytical solutions and with the help of numerical methods.

Keywords: *corrosion, anticorrosive coatings, optimization.*

Данное исследование посвящено созданию новой математической модели комбинированного подхода к учету коррозии и защитных свойств антикоррозионных покрытий. В качестве базового уравнения коррозии используется модель Долинского, которая позволяет учитывать влияние напряжений на коррозионный износ конструкций. Реализация данной модели продемонстрирована на примере оптимизации изгибаемых элементов прямоугольного сечения. Поэтапно получены аналитические решения по определению поперечных размеров и времени полной потери антикоррозионного покрытия данных элементов. В результате оптимизации найдены оптимальные начальные размеры сечения по критерию минимального объема конструкции. Предложенная модель, а также рассмотренный подход к ее реализации при оптимизации конструкций, работающих в условиях коррозии, могут быть использован как при аналитических решениях, так и с помощью численных методов.

Ключевые слова: *коррозия, антикоррозионные покрытия, оптимизация.*

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