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# Development of calculation and design of rotor-blade engine N.N. Tverskoy with a built-in electric generator

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**Abstract**. Current requirements are considered for an autonomous source of power supply for powering a consumer located in areas remote from a centralized power system in comparison with the method of connecting to a centralized power system, using a petrol, diesel and power plant using a Stirling engine with external heat supply in this article. The main aspects are identified power plants with external heat supply, analysed materials that support combustion, which can be used to operate an autonomous generator. The history is described and the purpose of the rotary engine of the Russian engineer N.N. Tverskoy. An economic assessment and engine performance have been considered, in which superheated steam is not required to be used, but steam with droplets of liquid for use is permissible. The design proposed rotary vane engine N.N. Tverskoy with a built-in electric generator, in which the expansion part (turbine) and the generator represent a single joint part. The design methodology is considered, in which the main sections on the calculations and design of the rotary machine with the main empirical formulas are highlighted. Further ways of using the engine are described in the low-grade heat recovery system.

## 1. Introduction

All spheres of human activities associated with electricity today. One day without electricity, like a difficult challenge for the modern man and for the company, which operates large amounts of data, in real conditions of a disaster. Serious demands on the reliability and continuity of power supply are applied to the centralized power supply on the basis of the relationship between various kinds of human activities from electricity at the moment. The question arises: people in the areas as to be remote from centralized energy system and those who impact natural disasters create long breaks in power supply.

Electricity by attaching to the centralized energy system of the object line 6-10 kV is very limited in power and length of paving of the line, the more power consumption of the consumer (up to 250 kW), the shorter may be the power lines. The building is inexpedient, the power lines 35 kV and above, the line will work in the regime close to the idling speed at small transmission capacities, the economic efficiency of capital investments is reduced to zero [1].

Scientific-technical progress develops the production of electricity using power plants based on renewable sources of electricity to use their autonomy from the centralized energy system. Renewable energy sources are developing, and this is due to the efforts and concern about greenhouse gases that influence global climate. Reduction of dependence on imports of energy and raw materials to power plants is also a very important aspect of renewable energy development. Events, analyzing the latest time you may notice a reduction in the consumption amount of raw material needed for energy pro-

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duction by the countries of Europe. It can be concluded on the basis that renewable energy sources play an important role in the energy policy of the European Union. But given the fact that renewable energy can create some difficulties in offline and distribution network due to its oscillatory nature, use plants for organic fuels for redundancy [2].

## 2. Materials and Methods

Diesel and petrol are the most common small (up to 10 kW) autonomous power plants now that use internal combustion engines, and we also highlight the not so common one - the Stirling engine, which can be used in a cycle with external combustion. The engines presented have a number of advantages and disadvantages, which we highlight in Table 1 and Table 2.

**Table 1.** Advantages of a power plant with a petrol, diesel or Stirling engine.

| Diesel | Petrol | Stirling with external heat input |
|---|---|---|
| Lack of ignition system | Affordable cost | Closed loop work |
| Work resource | Service | Low noise |
| Economical consumption | Noise level | Ability to work on various types of fuel |
| Quick spread | Quick spread | Partial load characteristics |
| Power | | Efficiency at low ambient temperatures |

**Table 2.** Disadvantages of a power plant with a petrol, diesel or Stirling engine.

| Diesel | Petrol | Stirling with external heat input |
|---|---|---|
| Noise level | Fine tuning the intake / start system | System warm up required |
| Whimsical to fuel quality | Whimsical to fuel quality | Efficiency 15-25% |
| Service cost | Fuel consumption | Slow application progress |
| Crank mechanism | Crank mechanism | Crank mechanism |
| | | Communication with the generator through the shaft |
| | | Overall dimensions |

The use of a small autonomous power station (petrol, diesel fuel) creates storage restrictions, and requires constant monitoring of the amount of fuel in conditions of remoteness from gas stations. The use of a power plant with a Stirling engine with an external heat supply allows us to rely on materials that support combustion, the specific heat of combustion in atmospheric air of which is presented in Table 3. Taking into account the shortcomings of the Stirling engine shown in Table 2, it can be concluded that the operation of this system and its resource of work, but one should not miss the advantages that are decisive in the face of a limited supply of petrol (diesel fuel).

The advantages of the system on an external heat supply, taking into account the design flaws of the Stirling engine, should be taken into account that the engine is necessary for efficient operation, in which there is no: a crank mechanism and a shaft between the engine and the generator through which torque is transmitted. An engine which does not have the above items has a longer service life due to the reduction in the number of components of the motor structure and the loss on the shaft will be excluded when transmitting torque. It remains only to determine the choice of working fluid for the engine to work with an external supply of heat.

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**Table 3.** Characteristics of materials that support combustion.

| Substance | Calorific value, MJ/kg |
|---|---|
| Propane | 47.54 |
| Petrol | 44 |
| Diesel fuel | 42.7 |
| Household gas | 31.8 |
| Firewood | 14.4-17.4 |
| Waste * | ≈17.0 |

*the calorific value when burning waste of fabric, nylon, nylon, rubberized fabric, impregnated PVC fabric, polystyrene foam, household waste, paper, plastic film, rags, PVC, wood waste is at least 17 MJ/kg.

## 3. Results

The idea arose of the design of a rotary machine for a submarine by the engineer-mechanic of the fleet of the Russian Empire Nikolai Nikolayevich Tverskoy in 1876 (Figure 1) [3]. A true rotary machine differs from engines with a crank mechanism in its symmetry, small number of rotating parts, simplicity of design and rotation by a working fluid (freon), which is heated outside the closed loop of the system according to the ORC (Organic Rankine Cycle) duty cycle.

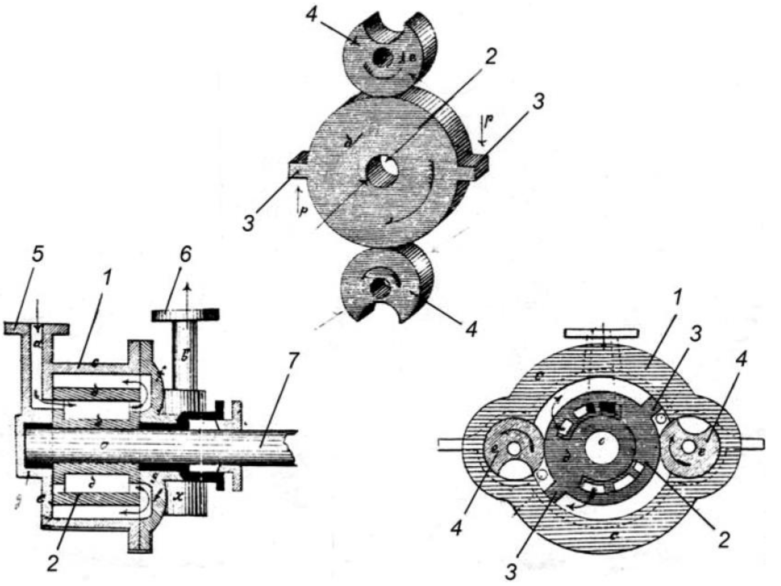

**Figure 1.** Diagram of a rotary machine designed by N.N. Tverskoy (1 - housing, 2 - rotor, 3 - pistons, 4 - sealing rollers, 5,6 - steam supply and exhaust pipes, 7 - shaft).

Rotary vane engine N.N. Tverskoy with an integrated electric generator combines the advantages of a rotary machine, and also has a longer service life due to the reduction in the number of components of the motor structure, increased efficiency due to the use of heat losses from the generator, which additionally heats the working fluid and eliminates shaft losses during transmission of the rotary moment (Figure 2) [4]. The unified design of the engine - generator is an integrated module.

The spread of devices with a blade structure is slow at present, but I would like to note the invaluable potential of these machines. Unlike turbomachines, the production of this design is relatively inexpensive, and as a result, the price will be attractive for the final product using a vane engine. The mode of operation is weakly dependent on dynamic effects, in contrast to the transmission of torque in a turbine associated with the movement of a liquid, steam or gas, which means that overheating of the working fluid is not required. If we don’t need overheating of the working fluid, then the area of the calculated heat exchanger will be less, and this increases the economic viability of the system, calcu-

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lated according to formula 1. Thus, this apparatus is suitable for efficient operation under any working fluid, as well as for working with mixtures. On the contrary, working with a working fluid in which there will be liquid seals the gaps between the rotor and the housing and the rotor, and the sealing rollers improving lubrication. Capital costs for the production of such an apparatus are reduced due to improved lubrication. In addition, adequate requirements should be noted when designing the pistons (blades) of the engine N.N. Tverskoy and the possibility of combining with a generator without gear links [5].

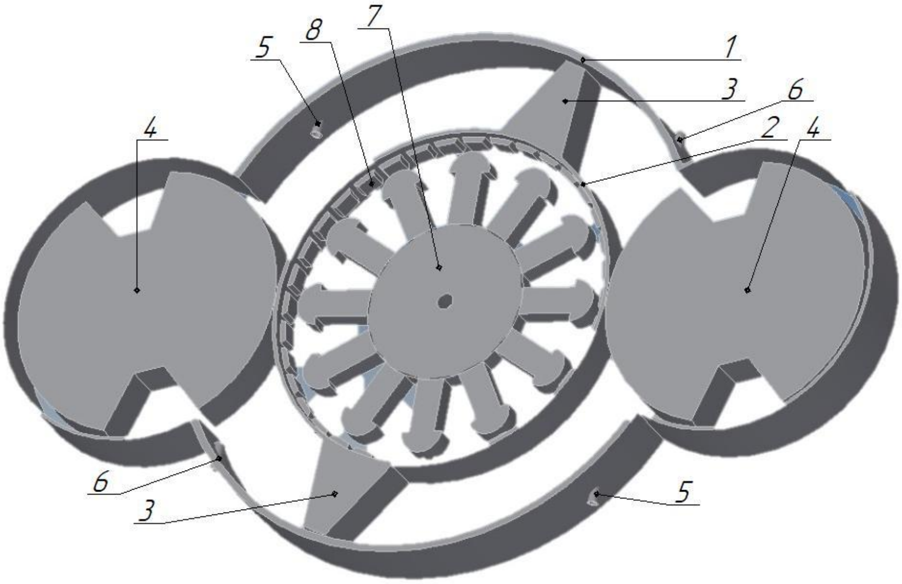


**Figure 2.** Diagram of a rotary vane engine N.N. Tverskoy with a built-in electric generator (1 - housing, 2 - rotor, 3 - pistons, 4 - sealing rollers, 5,6 - supply and exhaust pipes of the working fluid, 7 - stator, 8 - permanent magnets).

$$E = \frac{Q}{N}, \tag{1}$$

$$E = \frac{G \cdot c \cdot \Delta t_{\max}}{V \cdot \Delta p},$$

where *E* is the total heat capacity of the apparatus, Q is the heat transferred through the heat exchange surface, N is the work spent to overcome the hydrodynamic resistance, G is the mass flow rate of the coolant, kg / s, s is the heat capacity of the coolant, kJ/kg * K, $\Delta t_{max}$ - the maximum temperature head or the difference between the initial temperatures of the coolants, K, V is the volumetric flow rate of the coolant, $m^3$ / s, Δp is the hydrodynamic resistance, Pa [6].

The movement is converted from the pressure of the working fluid, which drives the rotor with pistons (blades) on which the permanent magnets are located on the inside. When the engine is running, the pressure of the working fluid on all the parts, the magneto dynamic coercive force, the inertia and friction forces, which depend on the various operating modes of the apparatus, act. Therefore, the following design sequence is possible in the calculation method of the rotor-vane engine N.N. Tverskoy with a built-in electric generator [7, 8].

Input of initial data for designing the apparatus: power N, angular velocity ω and torque on the rotor M. Power N is determined by the load schedule N (t) for a given time interval by the formula 2. Given the number of revolutions per unit time, ν we determine the torque M by the formula 3.

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$$N_{н} = \frac{1}{\eta \cdot \tau} \int_{0}^{\tau} N(t)dt, \tag{2}$$

$$M = \frac{N}{2 \cdot \pi \cdot v}, \tag{3}$$

Calculation of the parameters of the expansion part of the rotary vane engine: the flow rate of the working fluid according to formula 4 and the area of the piston (blade) working surface [9]. The gap between the casing and the pistons (blades) is set to 50 microns (0.002 inches).

$$M \cdot c_v \cdot dT + p \cdot dV + dQ_w = 0, \tag{4}$$

where M is the mass of the working fluid in the chamber; $c_v$ is the specific isochoric heat capacity of the working fluid; T is the temperature of the working fluid in the chamber; p is the pressure of the working fluid in the chamber; V is the volume of the working chamber; $dQ_w$ is the heat given (received) by the working fluid as a result of heat exchange with the walls of the chamber.

The choice of the working fluid, the calculation and the selection of the heat exchanger for the working fluid for the parameters of the amount of heat input from the type of material (fuel) that supports combustion according to Table 3 according to the formula (5).

$$Q = K \cdot F \cdot \Delta t_{cp} \cdot \tau, \tag{5}$$

where Q is the heat flux, F is the heat transfer surface, K is the kinetic coefficient of heat transfer characterizing the rate of heat transfer, Δtav is the average temperature difference over the heat transfer surface, and τ is the time.

The pressure of the working fluid at the inlet to the apparatus is calculated, the thermodynamic parameters necessary for calculating the geometry of the structure are determined.

Design and construction of rotor-blade engine parts.

Performing power, strength and dynamic calculations for the engine design with the aim of determining inertial parameters, centering the rotor stroke and other strength characteristics.

Modeling engine operating modes in the software package.

Electric power is calculated by the obtained thermodynamic and inertial parameters to determine the geometric data and the stator winding of a synchronous permanent magnet generator.

The inductive parameters of the synchronous generator are calculated, and the inductances are calculated using the formula 6. Mathematical modeling of the engine - generator system is performed in the Matlab Simulink software package to obtain the machine operating mode.

$$L = \frac{\Psi}{I}, \tag{6}$$

$$\Psi = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (\psi_i - \psi)^2},$$

$$I = \sqrt{\frac{1}{n} \sum_{i=1}^{n} i_i^2},$$

where $L$ is the inductance, is the rms value of the flux linkage of the phases, $I$ are the phase currents.

Design of the design of the stator and external rotor with slots for permanent magnets, as well as a bearing operating at high temperatures.

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The thermal calculation of the synchronous generator to determine the necessary characteristics of the materials used in the generator, taking into account the temperature in the expansion part of the rotor-blade engine N.N. Tverskoy.

Design and assembly of the structure to determine the integral weight and size characteristics of the rotary vane engine N.N. Tverskoy with a built-in electric generator.

Design and calculation of the engine-generator control system according to the scheme depicted in Figure 3 [10].

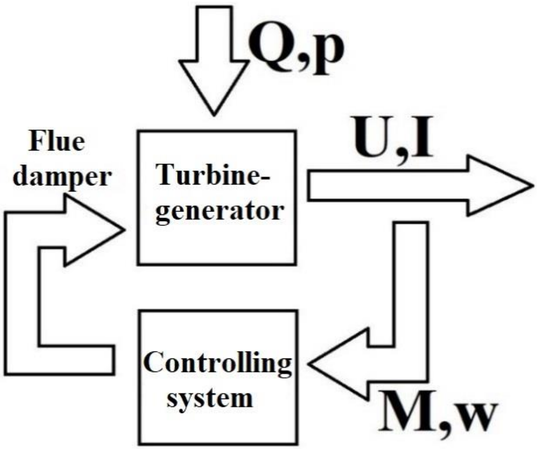


**Figure 3.** The control system of the rotor-vane engine N.N. Tverskoy with a built-in electric generator indicating the main parameters.

where Q is the heat flux, p is the pressure of the working fluid in the chamber, U is the voltage, I is the current, M is the torque, ω is the angular velocity.

## 4. Discussion

Modern policies of many countries aimed at the production of electricity in a way that will not harm the ecological background in this area and terrain. The issue of "clean energy" remains open and active for discussions at the world conferences and forums on the background of global warming and world climate change. I would like to note that the policy is widely distributed in the field of ecology, particularly in the industrialized States, but differs from the actual use virtually much. Significant result are possible to obtain when planning ecological development involving several sectors of the state fuel and energy complex, economy and Finance, natural farming, urban planning, agriculture and transport. It is possible to achieve maximum efficiency from the operations only at the intersection of interaction of state sectors [11-13].

Rational use of natural resources distributed generation when using recycled materials from human and animal production of biogas is rapid direction in the development of environmental protection now. This is a Prime example of the synergy of the sector development of the fuel and energy sector and agriculture. The aim of the projects is the creation, development and application of technologies, equipment and systems for the efficient production, collection and processing of various biological and manmade materials. Example of a research program in this direction: the increasing use of alternative energy source – biogas. The biogas produced from processing agricultural waste: animal and vegetable origin. Further development of the technology of using biogas as an alternative to considering natural gas, should take into account the efficiency of the first 30-50% less in comparison with the second [14-16].

The development of alternative sources of energy will have a positive impact on the environment, but also of note is the energy that is produced by thermal, nuclear, power plants, and then just disappears into the atmosphere in the form of heated air. Energy are not fully utilized and a great loss not only lowers the efficiency of the equipment, as well as adversely affect global climate change because of the huge number of low-grade thermal energy, emitted into the atmosphere. Application of technologies for utilization of low potential energy production is the solution, thereby increasing the overall efficiency of the station, and also positively affects the development of the municipal districts.

Technology for utilization of low-potential heat based on ORC. In the ORC is used as the working fluid with a low boiling working body (freon), which have a low boiling point at atmospheric pressure that allows to reach the required system parameters when using waste heat from power plants. The application of technologies for utilization of low-grade heat hides additional economic and ecological effect from the introduction of this heat recovery system the exhaust [17-19].

## 5. Conclusion

Design of a rotary engine should be considered at the same time due to the combined design of the thermal and electrical parts, as well as the ability to take into account the operation of the expansion apparatus for a couple in which there are drops of liquid. The conducted studies allow us to conclude that the potential and practical applicability of the design of the rotor-vane engine N.N. Tverskoy. The topic of the environmental problem is topical and requires consideration from all possible sides and involving modern technologies, new solutions and public sectors.

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