Opportunity of external combustion engines usage in forestry complex

E Tihonov, V Bazykin, N Mukhanov

1 Institute of Forest, Mining and Construction sciences, Petrozavodsk state university, 33 Lenina Street, Petrozavodsk 185000, Russian Federation
2 Laboratory of engines, Federal Scientific Agroengineering Center VIM, 45 Pushkinskaya Street, Pushkin 751000, Russian Federation
3 Department of mechanization, Ivanovo State Agricultural Academy named after D. K. Belyaev, 12 Lenina Street, Ivanovo 552000, Russian Federation

*Corresponding email: tihonov@psu.karelia.ru

Abstract. Considered problem of forest industry enterprises energy supply. Are taking in account following: energy communications remoteness, high cost of accessing to energy networks if they are near to logging site. Most of remoteness logging sites are energy supplied by diesel power plants. This situation leads to problems: high price for 1 kW, expenses fuel transportation. Observed possibility of Stirling engine usage in forest industry. First of all – electric generator based on Stirling engine, which allow to use biofuel. Considered possible schemes of Stirling engine usage. Co-generation scheme – secondary heat utilization. Direct generation with different biofuel usage. Defined the range of required Stirling power stations powers for forest industry. Was analyzed Stirling engine kinematic schemes: α, β and γ-type. Are defined more suitable type to use in logging sites - α-type. Air was selected like working body. Were analyzed mail difficulties of Stirling engine construction. The absence of calculation technique and experimental experience are show necessarily of construction parameters and heat-mass transfer analysis. Further issues of investigations were defined: complex and multiparameter numeric modeling of Stirling engine operational process with different power ranges and optimal construction parameters finding out for successful introduction of Stirling engine in forest industry were defined.

1. Introduction

Currently, wood harvesting is connected with spaces development that are more and more remote from mail infrastructure objects. Concerning this in the wood harvesting cost price the transport component is increasing [1]. This cost price component is concern not only with wood transportation directly. Most part of logistic costs is consumed to diesel fuel delivery including for electric-generators, which provides remote wood areas livelihoods [2]. Diesel-generator often is only one available source of electric energy in wood harvesting objects. More than that, in different regions of Russia, especially in arctic and sub-arctic regions, there are localities, which have only one source of electric energy – Diesel electric station (DES). For example, in Irkutsk region there are about 100 localities that are energy supplied only during 6 hours per day per DES. The cost of such electricity is 13.5 times higher than the cost of grid electricity [3].
Connection to the grid system of logging enterprises is not a solution to the issue, even with the relative proximity of power lines. This is due to the high cost of connectivity (coordination and design work) and the mobile nature of the logging infrastructure. Therefore, today, DES are used everywhere. Such a power supply scheme has the following disadvantages: poor environmental performance, noise, the need for transportation and proper storage of fuel reserves, the high cost of 1 kW·h of electricity (for obtaining 1 kW hour 0.2 liters of diesel fuel is burned [4]).

One of the ways to solve this problem is the development and implementation of a line of generators of various capacities based on a Stirling engine. Stirling engines are known for a long time [5], their development and improvement were based on the basic principles of thermodynamics and a huge amount of experimental research [6]. However, these engines could not sustain the pace of development, with a well-developed theoretical base of internal combustion engines. At the moment, the efficiency of Stirling engines is lower than the efficiency of diesel engines of the same power. At the same time, in the context of the problem under consideration, it should be taken into account that the fuel for the Stirling engine can be used for woody biomass, which is abundant in each cutting area [7]. Technological capabilities and procurement schemes with further combustion of chips for the drive of external combustion engines are considered in a number of publications by Anisimov and Onuchin [8].

This type of fuel is perfect as an energy source for a power station based on a Stirling engine (SES).

In our opinion, the introduction of SES at logging enterprises will improve the economic and environmental efficiency of the industry. In comparison with DES, SES will have the following advantages: environmental friendliness, low noise, no need to deliver expensive fuel.

At present, the market does not include SES, or serial engines that meet the operating conditions of logging enterprises. The serial production of industrial Stirling engines has not yet been mastered in any country in the world. Although they were produced in the XIX century, before the widespread introduction of internal combustion engines [9]. There are experimental samples, as well as engines for specific needs (power plant for submarines [10]).

In this regard, it is necessary to develop SES working on wood biofuel from scratch. This will require significant resources, and before starting work it is necessary to assess the potential of this idea, the possibility of a wider use of SES at all stages of the logging and wood processing industry. To assess the comparative efficiency of the SES, you need to decide on a number of questions: a basic installation diagram, a type of Stirling engine, a range of operating powers, a working fluid, an acceptable efficiency.

### 2. Methods and materials

The most effective scheme for the use of SES installation is cogeneration [11]. When heat energy from the main engine, or another source of secondary heat, is used as an additional source of heating of the working fluid in the Stirling engine. In the conditions of logging enterprises such a source can be: boilers of a heating system, exhaust gases of drying units and diesel power plants directly. The main source of heat will be solid biofuel available in sufficient quantities: sawdust, chips, peat, bark, and other logging residues. In certain cases, pure cogeneration is possible (for example, wood processing plants). Average temperatures of these heat sources are given in Table 1 [12-14].

**Table 1. Average burning temperatures of heat sources.**

| №  | Source type                      | Temperature, °C | Specific heat of combustion, MJ/kg |
|----|----------------------------------|-----------------|-----------------------------------|
| 1  | Sawdust normal humidity (pine, birch) | 400             | 8.37                               |
| 2  | Wood chips                       | 450             | 10.93                              |
| 3  | Bark                             | 450             | 5.69                               |
| 4  | Logging waste                    | 350             | 8.12                               |
Based on the foregoing, we will form a list of possible schemes for the use of SES in the conditions of logging enterprises:

Cogeneration schemes:
- DES - SES;
- heating boiler - SES;
- gases of drying chambers - SES.

Direct generation schemes (by type of heat source):
- waste of logging;
- chips;
- bark;
- sawdust.

Further, we define the required power range for the production site of a logging company. For evaluation we will rely on the winter period. The main groups of consumers are as follows: residential premises (change houses), illumination of the site, engineering support structures. Estimated power consumption and quantity are shown in Table 2.

**Table 2.** Objects of logging enterprises energy consumption.

| Consumer group          | Quantity | Consumption power, kW | Summary consumption power, kW |
|-------------------------|----------|------------------------|-------------------------------|
|                         | min      | max                    | min                          | max                          |
| 1 Change house 6x2,5    | 4        | 25                     | 2                            | 8                            | 50                            |
| 2 Spotlight             | 2        | 12                     | 0.1                          | 0.2                          | 1.2                           |
| 3 Engineering module    | 1        |                        | 3                            | 3                            |

Total: 11.2 54.2

Next, you need to decide on the type of Stirling engine. To date, there are 3 main schemes of the Stirling engine [5]:
- α-type;
- β-type;
- γ-type.

Also, there are many different schemes of Stirling engines combining basic types and applying other principles (for example, hybrid schemes [15]). Engine diagrams are shown in Figure 1.
The principle of operation of Stirling of any type is the same and is described in detail in the literature [9]. The criteria for comparative analysis of these schemes can be summarized as follows: the possibility of complete balancing, power density, design complexity, real-attainable efficiency [16]. The results of the analysis are presented in Table 3.

| №  | Stirling engine type | Full balancing | Power density | Constructive complexity | Efficiency |
|----|----------------------|----------------|---------------|-------------------------|------------|
| 1  | α-type               | No             | Average       | Low                     | High       |
| 2  | β-type               | Yes            | High          | High                    | Average    |
| 3  | γ-type               | No             | Low           | High                    | Low        |

The working fluid used in Stirling engines can be implemented using different gases: air, oxygen, helium, hydrogen [3]. In this case, the most effective will be the use of helium and hydrogen [8]. The main difficulty with the use of helium and hydrogen is the high diffusion of these gases through metals and compaction. In general, the issue of sealing the working fluid is one of the fundamental problems of improving the efficiency of Stirling engines.

### 3. Results and discussion

The optimal scheme for the implementation of SES in the conditions of logging enterprises is a direct generation scheme, adapted for the use of logging waste.

During the operation of SES in the conditions of wood processing enterprises, a cogeneration scheme is suitable, in which heat from heating boilers operating on chips, bark and sawdust is used to drive SES. The use of heat from the gases of drying chambers does not seem promising due to the insufficiently high temperature of these gases.

According to Table 2, we define the required power range of SES from 12 to 60 kW.

Based on the analysis of various Stirling engine schemes, the α-type is the most promising for further development. Low structural complexity and the possibility of significant separation of hot and cold cylinders will allow to obtain high performance indicators in the conditions of logging enterprises, while ensuring an acceptable resource and reliability.

The use of any gases other than atmospheric air as a working fluid entails both fundamental problems (leakage of the working fluid) and the need to deliver gas reserves to the SES operation site, which can be compared with the delivery of fuel for diesel power plants.

### 4. Conclusions

The Stirling engine, as a drive of a power plant generator, operated in the conditions of logging enterprises, is a promising direction of applied research. The introduction of a SES operating on waste
forest procurement, instead of a diesel power plant, will solve several issues: fuel supply, noise pollution, pollution of the combustion products of diesel fuel, and, most importantly, recycling of logging wastes. In general, this will reduce the costs of logging [17].

To successfully accomplish the task, it is necessary to develop a methodology for the development and design of Stirling engines adapted to the appropriate fuel and providing the required generator power (from 12 to 60 kW). Since scaling of the Stirling engines radically changes the processes of heat and mass transfer [14], it is necessary to investigate several power ranges to determine the optimal design parameters of Stirling engines. To determine the boundaries of these ranges, it is necessary to perform a sequential, multiparameter optimization of the structure with a gradual increase in power. The solution of this problem is associated with the enormous complexity of manufacturing a large number of experimental samples. Today, this problem can only be solved using the methods of numerical simulation of gas-dynamic and thermal parameters for the kinematic and dynamic parametrization of the mechanical part of the structures under study.

References
[1] Syunyaev V S and Sokolov A P 2008 Comparison of logging technologies in logging companies of the Republic of Karelia (Joehnsuu: Publishing Institute of Forest Research Institute of Finland) p 126
[2] Sokolov A P and Gerasimov Yu Yu 2013 Functional logistics of a logging company / Ministry of Education and Science of the Russian Federation, Federal State Budgetary Institution of Higher Professional Education Petrozavodsk State University (Petrozavodsk: PetrSU publishing house) p 84 ISBN 978-5-8021-2061-3
[3] Suhodolov A P, Fedorov V F and Horohonov D Yu 2004 Diesel power plants of the Irkutsk region and the problems of power supply of remote settlements News of the Irkutsk State Economic Academy 3 pp 25-27
[4] Diesel generator consumption // http://machineries.ru/ URL: http://machineries.ru/a_19.html (data of the application: 06.12.2018)
[5] Kuban L A 3D-CFD study of a Gamma-type stirling engine Energy 142-159. doi:10.1016/j.energy.2018.12.009
[6] Ahmed F. Numerical modeling and optimization of beta-type Stirling engine Applied Thermal Engineering, 385-400. doi:10.1016 / j.applthermaleng.2018.12.003
[7] Syunev V S 2014 Energy use of woody biomass: harvesting, transportation, processing and incineration: a training manual for university students enrolled in the areas of training "Forest Business", "Technological machines and equipment" and "Technology of logging and wood processing industries" / Ministry of Education and Science of the Russian Federation, Federal State Budgetary Establishment of Higher Professional Education Petrozavodsk State University / – (Petrozavodsk: PetrSU publishing house) p 123 ISBN 978-5-8021-2233-4
[8] Onuchin E M and Anisimov P N 2014 Development of circuit design solutions for elements of an external combustion engine with a device for the preparation, supply and combustion of wood fuel. Proceedings of the Volga State University of Technology. Series: technological. 2 pp 190–199
[9] Mendoza Castellanos L S Experimental analysis and numerical validation of the solar Dish/Stirling system connected to the electric grid. Renewable Energy 135 259-265 doi:10.1016/j.reneene.2018.11.095
[10] Zamukov, V. V. Sidorenko, D. V. 2012 Choice of air-independent power installation of non-nuclear submarines / Shipbuilding 4 pp 29–33
[11] Rasputin A L and Stepanov O A 2016 Using a Stirling Engine to Generate Electricity on Secondary Thermal Energy Resources / Energy and resource saving in heat and power engineering and social sphere: materials of the international scientific and technical conference of students, graduate students, scientists 1 pp 239–242
[12] Kudryavceva L A. 2009 Study of the burning features of sawdust / Modern problems of science and education. – 6 (3) pp 85-90

[13] Agapov D S 2016 The results of an experimental study of the effect of coolant temperature on the economic and energy performance of a diesel engine. Technical and technological problems of service 4 pp. 6–10

[14] Cyvin M M 1973 Use of bark (Moscow: Forest industry) p 96

[15] Açıkkalp E Solar driven stirling engine - chemical heat pump - absorption refrigerator hybrid system as environmental friendly energy system Journal of Environmental Management, 232 455-461 doi:10.1016/j.jenvman.2018.11.055

[16] Zare S Passivity based-control technique incorporating genetic algorithm for design of a free piston stirling engine Renewable Energy Focus 28 66-77 doi:10.1016/j.ref.2018.11.003

[17] Mihajlova V S 2016 Comparative analysis of the use of a Stirling engine and a diesel generator for the system of heat and power supply of objects in the Arctic regions of Russia / Young scientist 8 pp 261-265 URL https://moluch.ru/archive/112/28503/ (data of the application: 13.01.2019)