Review of the current state of research of microturbine units

N Myakishev\textsuperscript{1}, M Laptev\textsuperscript{2}, A Pekarskii\textsuperscript{2}, V Barskov\textsuperscript{1}, V Rassokhin\textsuperscript{1}, V Chernikov\textsuperscript{1}, E Semakina\textsuperscript{1}, V Yadikin\textsuperscript{1}, Y Matveev\textsuperscript{2} and A Smetankin\textsuperscript{1}

\textsuperscript{1}National Technology Initiative Center for Advanced Manufacturing Technologies based on the Institute of Advanced Manufacturing Technologies of Peter the Great St. Petersburg Polytechnic University Polytechnicheskaya, 29, St.Petersburg, 195251, Russia, v-rassokhin@yandex.ru
\textsuperscript{2}Higher school of power engineering, Institute of power engineering Peter the Great St. Petersburg Polytechnic University, Saint Petersburg, Polytechnicheskaya, 29, St.Petersburg, 195251, Russia

Abstract. The article provides an overview of the current state of micro-turbine units with an external supply of heat. In particular, there have been described various approaches of companies to the creation of this type of units, priority directions of micro-turbines design have been identified, too.

1. Introduction
Micro-turbine units are regarded to be a new type of micro-turbines which are used to solve applied problems of energy generation. At cogeneration mode, this type of units is able to solve the problems of heat supply for various objects. This type of units accepts wide variety of fuel. Micro-turbines are also used in residential areas, gas platforms and villages [1].
It should be considered that the energy saving system is now in crisis because the development of the generation capacity does not keep up with the increased consumption, therefore micro-turbine is an effective solution for integrated energy security [2]. All things above considered, this topic can be regarded as relevant [3].
The system of centralized energy supply in Russia lives through the crisis, i.e. the equipment wears out and the development of generation capacity does not keep up with the increased consumption. Decentralized forms of energy supply of cities, towns and villages are a very real prospect in the emerged crisis. Marketing research, analysis of technical and operational characteristics showed that micro-turbine is suitable for mini-thermal power stations projects [4].
Micro-turbine units are used for:
• electricity and heat supply of construction projects in a city center or its suburbs, resort areas;
• own needs of boiler rooms;
• enterprises, industrial and telecommunication facilities and other facilities interested in independent energy supply;
• hospital complexes;
• sports facility. These are mainly swimming pools and water parks, by which both electricity and heat are in demand [5].
In Russia, serious works upon this type of units has not been carried out yet. The main development in this sphere was performed by foreign specialists, namely by the engineers from Capstone (the USA), Institute of Engineering Thermophysics, Chinese Academy of Sciences (China), MTT Micro Turbine
Technology BV (the Netherlands), Delta Motorsport (the UK), all of them have achieved significant results. All the companies held their studies in different directions and sought for their own way of solving the problem, so finally they got the results which are described further.

2. Overview of research and installations of foreign companies

2.1. Capstone Corporation

Capstone Corporation chose their own way, the main idea of which was the improvement of the thermodynamic model of Capstone C30 micro-gas turbine. The methodology was based on the genetic optimization algorithm where variable solutions and targets are set depending on the available experimental data. The results of the studied case underline the ability of the method to identify some inconsistencies in the experimental data and lead to a consistent thermodynamic reconstruction of the behavior of the micro-turbine [6].

As a result, there have been found out the lack of constructions on the micro-turbine that let achieve declared total efficiency value and effective capacity. For this purpose, a new methodology was accepted, which defined the optimal set of thermodynamic input data using the Euclidean norm to estimate the preferred solution.

Another direction, which improved rapidly, was devoted to the development of the method of rapid identification to obtain simplified dynamic models that were tested using the Capstone C30 micro-turbine [7]. For this purpose the model of the second order was identified through the adoption of the theory of sensitivity which included Lyapunov function that updates parameters of the model every time the physical system is changed. This characteristic can be effectively accepted to implement real models in simulations in the time domain, giving accurate results even if some internal parameters change. Several simulations and experimental tests were conducted in order to study the effectiveness of the proposed methodology in obtaining a simplified dynamic model.

The developed methodology was tested with the help of several simulations and experimental tests conducted at the Capstone C30 micro-turbine. The results showed that the suggested methodology can be characterized by reliability, self-adaptability, high accuracy, stability and good convergence rate.

2.2. Institute of Engineering Thermophysics, Chinese Academy of Science

At the Institute of Engineering Thermophysics at Chinese Academy of Sciences, a computational model of heat exchange and differential pressure was established to optimize the design of the ring heat exchanger in a micro-turbine with a transversely wavy primary surface [8]. The genetic algorithm method is used to solve the problem of optimization of a ring heat exchanger with several constructive variables.

Thus, the optimal approach of designing such type of a heat exchanger is formed. The reliability of the computational model is verified by comparing the results of calculations with experimental data of heat exchanger prototypes C30 and C65 (Capstone Turbine Corporation). Compared with the original design, the optimal design leads to a significant reduction in pressure loss if all the limitations are met, which proves that the formed optimal design approach is effective for the ring heat exchanger. Replacing the optimization goal, the approach to optimal design presented in this article can be used in a single-purpose optimization for other goals (compactness, heat transfer area, mass, volume, efficiency, etc.) and even in a multi-objective optimization in accordance with the specific requirements of various micro-turbines [9].

2.3. Institute of Engineering Thermophysics, Chinese Academy of Science

At this university the studies on the use of fast pyrolysis of bio-oil (FPBO) were held [10]. The studies were carried out on a small scale of non-regenerated micro-gas turbine, created in a special test unit [11]. The system includes an injection line and a modified combustion chamber to burn the effectively high volume parts of FPBO/ethanol. The effect from the increased volume of the combustion chamber increased the quality of combustion of the reference diesel oil and pure ethanol in relation to exhaust emissions while maintaining the same fuel consumption of the original configuration [12]. By increasing the volume fraction of FPBO [13], there was an increase of CO emissions in the fuel mixture, probably...
III Quality Management and Reliability of Technical Systems

caused by larger droplets derived from more viscous fuel, as well as increase of NOX emissions, which probably happened due to fuel-related nitrogen [14].

With the proposed modifications being taken into account and the FPBO/ethanol mixture accepted as fuel, the overall electrical efficiency of the engine was higher than that of the reference diesel fuel. The final launch with 100% FPBO feed showed unstable combustion with the presence of carbon deposits in the hot parts of the system, which showed that the current configuration requires further changes to achieve the goal. Some fundamental principles of the introduction.

Fundamental principles were developed for the further integration of improved solutions for the micro-gas turbine (MGT) for the delivery of viscous, acidic and aqueous fuel.

2.4. Inha University

Scientists from the Korean Inha University conducted a study to identify the most preferred cycle for the heat recovery system. For their experiment they took the Rankine cycle (ORC) and transcritical CO2 cycle (tCO2) [15], which were applied to the micro-gas turbine (MGT), subsequently a comparative analysis of productivity was made, too.

Non-constructive characteristics of two cycles with MGT (micro-gas turbine) load change were analyzed, too. According to the calculations, the output power of ORC [16] was higher than in the tCO2 cycle when MGT was running at full load. At the same time, the change in the output power during the change in the MGT load is greater in ORC. tCO2 output power becomes higher when MGT is running under partial load, namely below 75%. Consequently, CO2 is suitable for a heat recovery system that uses MGT exhaust gas in places where MGT must operate at low loads for many hours of its operation, while ORC is more suitable in applications where MGT can run at almost full load.

The results were as follows:

• by capturing heat from MGT operating at the target point, the additional power produced by using ORC is about 5.5% higher than that of tCO2. It is connected with the fact that in this case the heat that can be extracted from the HRU is bigger;

• when the MGT works at partial load, the change of the temperature in the inlet of the cold side of HRU is bigger in the ORC, if the MGT load is changed. Consequently, HRU tCO2 can recover more heat than HRU ORC when MGT is running at a partial load below 75%;

• the appropriate system should be selected according to the operating conditions. If MGT must work at low loads for many hours of operation, tCO2 is more suitable as a bottom cycle. ORC is more suitable for applications where the system can run at almost full load for the biggest part of its working time [17].

3. The review of the Russian studies in the sphere of micro-turbines

3.1. Peter the Great St. Petersburg Polytechnic University (MGTU-100)

The specialists from SPbSTU made the analysis, the main goal of which was finding methods of increasing the coefficient of efficiency for the cycle of a simple thermal scheme. For this purpose four schemes were analyzed, which were suitable for this type of micro-turbine units, and, as a result, their advantages and disadvantages were revealed [18].

At the end of the study the a thermal scheme of a two-shaft small-size gas-turbine with a compressor drive from a separate electric motor was chosen, as it possesses a simple design and high reliability. Some other very important advantages of this scheme include the drive of the compressor from a separate electric motor, with the help of which the increase of the coefficient of efficiency of MGTU-100 (micro-gas turbine 100) without using the recuperative air heater, and the absence of "surge" zones due to the variable speed of the compressor impeller.

3.2. Combined cycle gas compressor station "Severnaya", «Gazprom transgaz St. Petersburg»

On the basis of «Gazprom transgaz St. Petersburg», which is one of the biggest gas companies in Russia, the concept of the turbine-generators construction was formed, which use the energy of compressed natural gas for own needs of the “Gazprom transgas”. This concept let creating environmentally friendly sources of generating electricity without burning additional fuel [19]. Therefore the steam turbine unit
“MTU-500” was made, which worked on the basis of the ORC cycle. The main task was the creating a steam turbine on the basis of already existing prototypes. Apart from this, the emphasis was put on the increase of the coefficient of efficiency. While designing a unit, one also examined several variants of thermal schemes, where advantages and disadvantages of each scheme were revealed [20].

According to the results of the preliminary calculation, a scheme of a three-circuit power source based on the MTU-500 ORC was chosen, which is the most promising at the present considering both increasing efficiency through the use of residual heat for thermal needs, safety and easy operation.

4. Conclusion

To sum up, one may say that each company described above has chosen its own way of solving the problem touched upon in the article. For instance, Capstone in its study put the emphasis on the increase of coefficient of efficiency and useful power, while Chinese scientists paid their attention to the optimization of the ring heat exchanger. Scientists from University of Florence decided to create a turbine which works on bio-oil. As a result, the increase of efficiency coefficient of the engine compared to the reference diesel engine was achieved. The scientists from the Korean Inha University compared the organic Rankine cycle and the transcritical CO2 cycle, which were used in a micro-gas turbine, and afterwards the a comparative analysis of the productivity was made. The specialists from SPbSTU aimed to the increase of efficiency coefficient of MGTU-100 based on the analysis of thermal schemes. What about the company “Gazprom transgaz St. Petersburg”, there has been chosen the most promising scheme of a three-loop energy source.

References

[1] IntechOpen 2013 (https://www.intechopen.com/books/progress-in-gas-turbine-performance/micro-gas-turbine-engine-a-review [Electronic resource] [website])

[2] Min Jae Kim, Jeong Ho Kim and Tong Seop Kim 2018 The effects of internal leakage on the performance of a micro gas turbine Applied Energy p 212

[3] Kanareykin A 2012 Big role "small" energy Power and industry of Russia (20)

[4] Mikheev N 2013 Microturbines - an innovative technology for creating nuclear power NETWORK&BUSINESS (5)

[5] Microturbine is an effective solution for integrated energy security [Electronic resource] (electrosystems: [website]. URL: http://www.electrosystems.ru/experience.php (date accessed: 12.12.2018))

[6] Alfredo Gimelli R S 2017 Thermodynamic model validation of Capstone C30 micro gas turbine Energy procedia (126)

[7] Cagnano A and Tuglie E De 2018 On-line identification of simplified dynamic models: Simulations and experimental tests on the Capstone C30 microturbine Electric Power Systems Research (157)

[8] Jun Cai, Xiulan Huai and Wenzuan Xi 2018 An optimal design approach for the annular involute-profile cross wavy primary surface recuperator in microturbine and an application case study Energy (153)

[9] Aiguo LII and Yiwu WENG 2009 Effects of Lower Heat Value Fuel on the Operations of Micro-Gas Turbine Scientific Research (1)

[10] Hossain A K 2013 Philip Andrew Davies, Pyrolysis liquids and gases as alternative fuels in internal combustion engines - A review Renewable and Sustainable Energy Reviews (21)

[11] Poritosh Roy and Goretty Dias 2017 Prospects for pyrolysis technologies in the bioenergy sector: A review Renewable and Sustainable Energy Reviews (77)

[12] ResearchGate 2009 (https://www.researchgate.net/publication/285676129_System_identification_and_performance_improvement_to_a_micro_gas_turbine_applying_b_iogas [Electronic resource] [website])

[13] Woudstra T, Schoenmakers L, Oldenbroek V, Thallam Thattai A, Aravind P V 2016 Experimental model validation and thermodynamic assessment on high percentage (up to 70%) biomass cogasification at the 253 MWe integrated gasification combined cycle power plant Applied energy (168)
[14] Marco Buffi, Alessandro Cappelletti, Andrea Maria Rizzo, Francesco Martelli and David Chiaramonti 2018 Combustion of fast pyrolysis bio-oil and blends in a micro gas turbine Biomass and Bioenergy (115)

[15] Xurong Wang and Yiping Dai 2016 Exergoeconomic analysis of utilizing the transcritical CO₂ cycle and the ORC for a recompression supercritical CO₂ cycle waste heat recovery: A comparative study Applied energy (170)

[16] Joon Hee Lee and Tong Seop Kim 2006 Analysis of Design and Part Load Performance of Micro Gas Turbine/ Organic Rankine Cycle Combined Systems Journal of Mechanical Science and Technology 20

[17] Suk Young Yoon Min Jae Kim, In Seop Kim and Tong Seop Kim 2017 Comparison of micro gas turbine heat recovery systems using ORC and trans-critical CO₂ cycle focusing on off-design performance Energy procedia (129)

[18] Fokin G A 2015 Autonomous sources of electric and thermal energy for main gas pipelines and gas distribution stations Monograph (Moscow: FIZMATLIT)

[19] Fokin G A Methodology of creation of the Autonomous sources of electric energy using energy of the compressed natural gas for own needs of gas transportation system of Russia St. Petersburg: Peter the Great St. Petersburg Polytechnic University

[20] Zabelin N, Lykov A V, Rassokhin V A, Sivokon N V and G A Fokin 2013 Steam-gas plant compressor station "Severnaya" Science and technology in the gas industry (20)