An analysis of the viability of implementing steam screw machines at the facilities of energy generation enterprises to reduce the energy costs for their own need

D. S. Balzamov^{1,*}, I. G. Akhmetova¹, E. Y. Balzamova¹, G. I. Oykina², and Gelu COMAN³

¹ Kazan State Power Engineering University, Kazan, Russia

² National Research University "Moscow Power Engineering Institute", Moscow, Russia

³ "Dunărea de Jos" University of Galați, Romania

Abstract. Reducing the energy consumption for the own needs of energy sources is an urgent task that can be solved by organizing our own energy sources by using the potential energy of water vapor in steam screw machines. The article discusses some options for installing steam screw machines at the facilities of generating companies and identifies factors affecting the return on steam screw machines in the current operating conditions.

1 Introduction

At present, the energy-saving programs of enterprises engaged in the development and distribution of energy resources are aimed at reducing the resource-intensiveness of a unit of energy produced. That is why a continuous search for new technologies and technical solutions to reduce the consumption of energy resources for the needs of thermal power plants and production and heating boilers is carried out [1].

The main energy carrier of the stations is water steam, which, depending on the intended use, is characterized by different parameters. In most cases, this is steam with a pressure of 13 atm. In turn, technological needs require steam at 4.0 - 6.0 atm, and heating requires steam at 1.2 - 2.0 atm. Typically, the useful energy of pressure drop is irretrievably lost in a reduction cooling unit, which is a simple solution, though not energy-efficient.

Fig. 1. Steam-screw machine with a capacity of 1.0 MW.

A fairly promising solution for the beneficial use of pressure drop is the operation of steam screw machines (SSM), which can become the basis of mini-cogeneration heat plant (CHP), or are built into the thermal scheme of a thermal power plant [2].

2 Methods

During the technical re-equipping of generation facilities, to ensure reliable and efficient operation of the SSM, it is necessary to provide for the installation of the following auxiliary equipment:

To cool the vapor from a steam turbine, it is planned to install a vapor cooler with a stainless steel pipe system. Installing a vapor cooler makes it possible to minimize evaporation losses from SSM seals by utilizing condensation energy and heating the demineralized water of the existing station cycle.

To reduce the temperature of the steam before the SSM, the installation of a vapor cooler is provided.

For the continuous circulation of cooling water through SSM oil coolers, it is necessary to provide for the installation of at least two oil cooling pumps.

Existing SSM designs allow for the capacity range from 200 to 1500 kW to be covered. Table 1 contains the operating characteristics of SSM.

When operating in energy-saving mode, the power plant operates for the enterprise mains, covering part of its own energy needs and thereby reducing its consumption from the mains. RPM of the power plant is determined by the frequency of the alternating current in the mains. The capacity of the plant is determined by the pressure drop and the steam flow rate through the machine and is regulated by the throttle valve at the SSM inlet.

* Corresponding author: dbalzamov@mail.ru

Table 1. Operating characteristics of SSM depending on the steam parameters in the boiler room.

Inlet pressure, at	Outlet pressure, at	Steam consumption, t/h	Capacity, kW
12	2	5-24	320-1500
12	8	20-40	350-700
30	2	4-20	400-1900
10	3	8-36	330-1540
10	6	15-30	310-620
8	6	16-32	170-340
6	2	5-24	200-910

SSM automatic control and protection system, based on microprocessor technology, should take into account the different technical level of instrumentation equipment of boilers and CHP, allow the possibility of operating in conjunction with modern automated process control systems (PCS) based on personal computers, and also work independently in the boiler room and CHP with outdated instrumentation and automation equipment.

Advantages of using SSM over traditional steam turbine plants:

1. Due to the screw shape of the impellers, these machines can operate with a contaminated working media, for example, with steam containing mechanical impurities, condensed moisture. In addition, the minor steam condensation in the machine should not affect SSM impellers. If there are such impurities in the steam supplied to the steam-turbine plant, the resource of this plant is essentially reduced due to erosive wear of the blades. It can even lead to emergency situations associated with the destruction of turbine blades.

2. The range of SSM capacity control is 20 - 100% of the nominal SSM capacity. As a comparison, the range of capacity regulation of the steam turbine is 60 - 100% of the nominal value, while it is possible to reduce the capacity of some turbines to 30% of the nominal capacity only for a limited time.

3. For efficient use of a steam turbine, its minimum capacity limit should be 5 MW. The further reduction of the steam turbine capacity leads to a significant increase in its payback period.

Disadvantages of SSM:

1. Restrictions on the parameters of the operating steam due to problems with the tightness of the seal. The maximum operating steam pressure of existing SSM is 30 atm, while steam turbines can operate on steam with a pressure of 130 atm and more. As such, the volume of work done in a steam turbine, in this case, is much greater than in SSM. Thus, the rated capacity of existing SSM is substantially less than the capacity of steam turbines.

2. The steam turbine has one rotating shaft with turbine impellers mounted on it, and SSM has two shafts. As a result, there are more moving parts in SSM than in most steam turbines. This results in the complexity of designing and maintaining it.

Based on the above information, the existing SSM cannot replace steam turbines at power facilities, but at

the same time, their use at low capacities will reduce unit costs for the generation of energy unit.

Thus, it is reasonable to use SSM in the following cases:

1. To reduce and cool contaminated steam, or steam that is close to saturation;

2. When working with different reduction cooling units and fast-response reduction cooling units for useful work in reducing steam;

3. In low-capacity steam boilers for generating power for own needs;

4. To improve the quality of performance regulation at power plants, especially at low-power stations, due to the smooth change of SSM capacity and less time spent on powering it on and off.

There are several options for installing SSM for boiler and thermal power plants. The analysis of these options showed that installing an SSM would be appropriate if the number of existing heating steam extractions is not enough to cover the heat load, and this shortage is compensated by reducing steam from industrial extractions through reduction cooling units.

Otherwise, if there is no shortage of heat power from the heat extractions, then there is a risk of excess steam when bringing it back to the cycle, or inoperability of this plant in the absence of steam extraction at the plant outlet.

3 Results

Possible options for the use of SSM for power facilities in Kazan:

1. The SSM can be connected to the 30 atm steam pipeline to produce energy for its own needs at Kazanskaya CHP-1. To bring the steam parameters to the required values for the SSM, a reduction cooling unit (RCU) must be mounted onto the pipeline section between the 30-atm steam pipeline and SSM. Spent steam with a pressure of 1.2 atm can be further sent to deaerators, delivery water heaters, or to cooling and to the chemical water treatment plant.

The promising trend in the use of SSM for reducing steam and generating power for own needs is its parallel installation with the present reduction cooling unit RCU-13/1.2 at Kazanskaya CHP-1 (average consumption is 40 tons/hour). In this case, steam extraction for SSM in the amount of 19.8 t/hr should be carried out from the 13 atm pressure steam supply pipeline (to the reduction cooling unit through the regulating valve). In this case, the spent steam from SSM is discharged into the steam pipeline with a pressure of 1.2 atm. A simplified SSM binding scheme is presented in Figure 1

It is suggested to produce steam for SSM at Kazan CHP-1 in heat recovery boilers (HRB), which are part of GTP1 and GTP2, respectively, when operating at minimum capacity. These boilers are designed for heat recovery of combustion products of gas turbine drives of GTP-25/NK No.1 and No.2.

When GTP operates at the nominal mode, each heat recovery boiler produces 35 tons of steam per hour at a pressure of 30 atm and a temperature of 390°C.

Fig. 2. Parallel installation of SSM and reduction and cooling plant at CHP-1 (GTP1, GTP2 – gas turbine plant; AC – air compressor; CC – the combustion chamber; GT – gas turbine; CV – control valve; SSM – steam screw machine; RCU – reduction cooling unit; BU1, BU2 – boiler utilizer).

However, when GTP operates at minimum mode, the temperature of the combustion products is lower and not sufficient to heat the steam to 390°C. In this case, it is allowed to reduce the feedwater pressure at the boiler inlet so that the vapor pressure at the outlet is 17 atm. The steam capacity of the boiler, in this case, will be 19 - 20 t/hr and a temperature of 260 - 270°C, which is sufficient for normal operation of the SSM. Thus, the following scheme is proposed for operating the SSM: GTP operates at a minimal capacity. Combustion products enter the heat recovery boiler. Steam with a pressure of 17 atm, a temperature of 260–270°C, in the amount of 19–20 t/hr enters the SSM, where it expands to a pressure of 1.2 atm. After SSM, steam enters the 1.2-atm steam pipeline. This scheme of using SSM seems the most promising, because in this case, no additional consumption of sharp steam is required; it solves the problem of heat recovery of combustion products from gas turbines in the summer, when the heat consumption is minimal; installation of additional reduction cooling units is not required and there is no interference with the operation of existing equipment of high-pressure section (HPS) and intermediate-pressure section (IPS) of the CHP.

4 Discussion

To generate electric energy for the needs of Kazanskaya CHP-1, Kazanskaya CHP-2 and Naberezhnye Chelny CHP, the installation of a steam screw machine is economically feasible if the number of existing heat extractions is not enough to cover the heat load and this deficit is compensated by steam reduction from production extractions through RCU. Otherwise, if there is no shortage of heat power from the heat extractions, then there is a risk of excess steam when bringing it back to the cycle, or inoperability of this plant in the absence of steam extraction at the plant outlet.

References

- [1] Overview of advanced technologies for generating companies D.S. Balzamor, B.F. Timershin, *Modern Science* **2**, 26-29 (2017)
- [2] S.R. Berezin, *Energy Saving Technology Using Steam Screw Machines / Teploenergetika*. **8**, 43-45 (2007)
- [3] H. Taniguchi, K. Kudo, W.H. Giedt, I. Park, S. Kumazawa, *Analytical and Experimental Investigation of Two-Phase Flow Screw Expanders for*

Power Generation. J. Eng. Gas Turbines Power, **110**, 628–635 (1988)

[4] D. Margolis, L. Analytical, Modelling of Helical Screw Turbines for Performance Prediction. ASME J. Eng. Power, **100**, 482–487 (1978)

[5] I. Tamura, H. Taniguchi, H. Sasaki, R. Yoshida, I. Sekiguchi, M. Yokogawa, An analytical investigation of high-temperature heat pump system with screw compressor and screw expander for power recovery. Energy Conversion and Management Volume **38(10–13)**, July–September, Pages 1007-1013 (1997)

[6] F.L. Litvin, A. Fuentes, *Gear Geometry and Applied Theory*. Cambridge University Press: Cambridge (2004)

[7] I.K. Smith, N Stosic, E Mujic, A Kovacevic, *Centre for Positive Displacement Compressor Technology*, City University, Northampton Square, London, UK The manuscript was received on 13 July and was accepted after revision for publication DOI: 10.1177/2041300910393429 (2010)

[8] H. Tabor, L. Bronicki, *Establishing criteria for fluids for small vapour turbines*. SAE Trans., 1965, 73, 561–575.

[9] B. Woods, *Alternative fluids for power generation*. Proc. Instn Mech. Engrs, 1969–1970, **184(40)**, 713–740

[10] S.S. Wilson, M.S. Radwan, *Appropriate thermodynamics for heat engine analysis and design*. IntJ.Mech Eng. Edu 5(1), 68–82 (1977)

[11] *NIST Reference Fluid Thermodynamic and Transport Properties Database (REFPROP)* US National Institute of Standards and Technology (2008)

[12] I.K. Smith, N. Stosic, A. Kovacevic, *Power recovery from low cost two-phase expanders*. In *Proceedings of the Geothermal Research Council Annual Meeting*, San Diego, CA (2001)

[13] B. Aoun, *Micro combined heat and power operating on renewable energy for residential building.*, Ecole des Mines de Paris (2008)

[14] K. Alanne, A. Saari Sustainable small-scale CHP technologies for buildings: the basis for multi-perspective decision-making. Renewable and Sustainable; Energy Reviews **8**, 401–31 (2004)

[15] J. Harrison, book: *Small and Micro Combined Heat and Power (CHP) Systems*; ISBN: 978-1-84569-795-2; Stirling engine systems for small and micro combined heat and power (CHP) applications © Woodhead Publishing Limited, 179 (2011)