Options for organizing own sources of energy supply at the facilities of generating companies based on steam screw machines

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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 [1-3].

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.

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 [4].

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.

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      |

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.

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. The system should allow the possibility of operating in conjunction with modern automated process control systems (PCS) based on personal computers. Also SSM automatic control and protection system should work independently in the boiler room and CHP with outdated instrumentation and automation equipment [5-7].

Advantages of using SSM over traditional steam turbine plants:

- 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, 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.
- 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.
- 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:

- 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.

- 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:

- To reduce and cool contaminated steam, or steam that is close to saturation;
- When working with different reduction cooling units and fast-response reduction cooling units for useful work in reducing steam;
- In low-capacity steam boilers for generating power for own needs;
- 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

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.

GTP1, GTP2 – gas turbine plant; AC – air compressor; CC – combustion chamber; GT – gas turbine; CV – control valve; SSM – steam screw machine; RCU – reduction cooling unit; BU1, BU2 – boiler utilizor.

A reduction cooling unit RCU 140/1.2 is installed at Kazanskaya CHP-2. Since useful work is not performed when throttling steam from 140 atm to 1.2 atm, it is recommended to equip this unit with SSM - 1.0 and expand the steam in two stages (figure 2):

- 1st stage, throttling steam from 140 atm to 17 atm with its cooling to 210°C in reduction cooling unit, without generating useful power;
- 2nd stage, throttling in SSM from 17 atm to 1.2 atm with the generation of 1 MW electrical power.
Another possible direction of SSM use for steam reduction is its parallel installation with the RCU-14/1.2 operating at the CHP. In this case, steam extraction for SSM in the amount of 19.8 t/hr should be done from the 14-atm steam pressure supply pipe 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.

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. 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.

Figure 1. Parallel installation of SSM and reduction cooling unit at CHP-1.
As a source of steam, you can consider options for using steam from a production extraction of 10–16 kgf/cm² of a steam turbine of PT-65/75-130/13/2.5 type or to extract steam from a turbine of P-50-130/13 type with backpressure 10-18 kgf/cm², T = 250°C. In the latter case, steam parameters fully correspond to the passport values of the steam at the SSM inlet.

At Kazan CHP-2, the power unit is operated on the basis of two steam-gas units (SGT unit), which include gas turbine plants GTP PG6111FA with heat recovery boilers of E-114/16-8.1/0.7-535/218-3.8 type. In the high-pressure loop of the boiler, 8.1 MPa (81 atm) steam is produced, 535°C (Go = 114 t/hr), low-pressure loop - secondary steam of 0.7 MPa, 218°C (Gextr = 16 t/hr).

One of the options offered for SSM use is extracting steam from the high-pressure loop of heat recovery boilers. In this case, to bring steam parameters to passport values before SSM, it will be necessary to install RCU 81/18, in which the steam is reduced to 18 atm and cooled to 240°C. Another option to prepare steam for SSM is the partial extraction of steam from the high-pressure loop and the partial extraction of steam from the low-pressure loop, followed by mixing the two streams in an ejector. Steam consumption from high- and low-pressure loops is selected according to the requirement of providing steam at the outlet of the mixer with the following parameters: pressure 18 atm, temperature 240°C. Spent steam with a pressure of 1.2 atm in all options is discharged into a 1.2 atm steam collector.

For the generation of energy for own needs at the Naberezhno-Chelninskaya CHP (NChCHP), SSM can be connected to production extractions of steam turbines. Today, steam from production extraction is used for the heat supply of OAPO "KAMAZ". Steam consumption is 36 t/hr. It is possible that, in the future, the consumer will abandon this steam. In this case, it seems reasonable to use steam from the production extraction to provide it for SSM. The steam from production extraction has the following parameters: pressure 13 kgf/cm², temperature 270°C. To reduce the steam temperature and possibly slightly increase pressure, a steam-water ejector can be installed before SSM. The passive flow in the ejector will be steam from the turbine production extraction. The active flow in the ejector may be water extracted behind the feed pumps. Spent steam, with a pressure of 1.2 atm, can be further sent to the technological needs of NChCHP.

Two quick-operating reduction cooling units RCU 140/1.2 are installed on the starting collector of the Naberezhnye Chelny CHP. Since during throttling steam from 140 atm to 1.2 atm useful work is not performed, it is recommended to equip this unit with SSM-1.0 and expand the steam in two stages:

1st stage - throttling steam from 140 atm to 17 atm with its cooling to 210°C in reduction cooling unit, without generating useful power;
2nd stage - throttling in SSM from 17 atm to 1.2 atm with an output of 1 MW electrical power.

Another possible option of using SSM for steam reduction is its parallel installation with the existing RCU-13/1.2 kgf/cm² at CHP. In this case, steam extraction for SSM in the amount of 19.8 t/hr should be carried out from the steam supply pipeline with a pressure of 13 atm to the reduction cooling unit, without generating useful power 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.
4. Conclusion
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.

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