ISSN 0040-6015, Thermal Engineering, 2014, Vol. 61, No. 12, pp. 861–863. © Pleiades Publishing, Inc., 2014.
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Some Matters Concerned with Selecting Steam Parameters and Process-Circuit Solutions to Optimize the Parameters of Steam Turbine Equipment and Engineering Design Developments

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Abstract—The possibility and advantages of increasing steam pressure in the steam-turbine low-pressure loop for combined-cycle power plants are considered. The question about the advisability of developing and manufacturing steam turbines for being used in combined-cycle power units equipped with modern class F gas turbines for supercritical and ultrasupercritical steam parameters is raised.

Keywords: steam turbine, combined-cycle power plant, optimization of parameters, supercritical parameters, efficiency, lifetime of parts

DOI: 10.1134/S0040601514120040

At present, a set of investigations is being carried out at the Ural Turbine Works (UTZ), aimed at achieving better technical–economic indicators of the cogeneration steam turbines developed by the UTZ for modern combined-cycle power plants (CCPs).

The modern trends in the development of CCPs have determined the basic lines of improving their efficiency. Apart from selecting rational cycles and process circuits of CCPs, optimization of the main parameters of the designed power units is one of the most important objectives. It is important to note that the attained level to which the CCP efficiency is improved depends not only on the gas turbine unit (GTU), but also on the steam turbine unit (STU).

One of the projects completed by the UTZ is a T-63/76-8.8 cogeneration steam turbine [1] with two heating extractions, which is intended to operate as part of a PGU-230 combined-cycle plant equipped with a GTE-160-5 steam turbine produced by the Leningrad Metal Works (LMZ) or with a V94.2A turbine produced by Siemens and a heat-recovery boiler produced by EMAl'yans. Previously, the UTZ designed and manufactured a T-53/67-8.0 steam turbine for a PGU-230 combined-cycle plant [2] made as a two-cylinder set.

In the considered case, the objective that was set forth was to develop a single-cylinder turbine with a capacity of up to 100 MW with admission of high- and low-pressure steam, with steam extractions for two-stage heating of network water in heaters, and with a noncontrolled or a controlled process steam extraction.

The T-63/76-8.8 turbine has been designed with a loop-shaped steam motion arrangement in the cylinder, which consists of an inner and an outer casing. In this design, low-pressure (1.3–1.5 MPa) steam upstream of the combined stop and control valve (instead of the frequently used pressure level equal to 0.6–0.7 MPa) is supplied to the intercasing-space (ICS) chamber, which, after the flow is turned through 180°, receives steam that has passed the high-pressure part's (HPP) stages located in the inner casing. The HPP stages are designed so that the maximal steam pressure downstream of them and, hence, the maximal steam pressure in the ICS chamber corresponding to the maximal flow rate of high-pressure steam, were lower than the pressure of the supplied low-pressure steam.

With such design of the turbine, mixing devices for supplying low-pressure steam are not used [2–5], and the front end seal is made with a smaller axial size. High-pressure steam is supplied to the turbine via four pipes into the cylinder inner casing; the axial size of this steam supply arrangement is equal to the intermediate seal length. With such a design, it becomes possible to achieve the shortest distance between the axes of the support bearings and the required strength and rigidity of the rotor subject to the permissible static sag of the rotor and to the stresses arising in it. The economically optimal distribution of heat drops among the stages is achieved in making to this end the required number the necessary number of stages in the turbine flow path, due to which the compelled overloading is avoided in designing the flow path blade system, and the optimal velocity ratios in the blades are obtained during operation in the nominal modes. In

Main indicators of CCP-based power units for supercritical and ultrasupercritical pressures

Indicator	HP/reheat steam temperature, °C	
	560/565	580/585
Payback period, years	7–8	15–17
Lifetime of turbine parts and components (standard), thousand h	220 (guaranteed fleet) with the possibility of extending to 350	220
Service life, years	30 (guaranteed fleet) with the possibility of extending to 50	30
CCP efficiency, %	54.5	56.0

* HP/reheat steam temperature, °C

addition, better maneuverability characteristics are obtained, the end seal system is simplified, the optimal relieving of axial force is attained, etc.

The T-63/76-8.8 turbine has been developed with due regard of the above-described requirements for a capacity of 95 MW and for the conditions of operation as part of a 300 MW CCP with a new version of the GTE-160-7 gas turbine, in which after five years of its commissioning the Customer must modernize the GTE-160-4 turbine operating as part of the PGU-230 combined-cycle plant.

As regards steam extraction for process needs with a pressure of 1.4 MPa in the CCP, such technical solution allows process steam to be extracted from the heat-recovery boiler's low-pressure drum. If the consumed flow rate exceeds the generated one, the necessary additional steam flow rate is taken from the turbine ICS. By using such solution, it becomes possible to manage with a circuit solution without the need to simultaneously supply and extract steam at a pressure of 1.4 MPa in the turbine.

The above-described UTZ proposal to match the pressures of the low-pressure steam loop with the process steam extraction has been accepted by the customer and put forward to the general designer as a requirement for selecting the CCP equipment and to the heat-recovery boiler manufacturer for designing. For order's sake, it should be noted that the transition from the optimal (and therefore often used) LP steam pressure equal to 0.6–0.7 MPa to 1.4 MPa results in that the CCP efficiency in the nominal mode of its operation drops by approximately 0.15% (without process steam extraction and 100% load) [6]. However, such a comparison was carried out at the same value of steam turbine efficiency, whereas UTZ specialists have succeeded—with other things being equal—in improving the steam turbine technical–economic indicators by 1.5% by using the proposed turbine design, due to which the CCP efficiency is increased by approximately 0.5%.

In selecting CCP power units equipped with modern gas turbines belonging to class F or higher (the gas temperature at the turbine inlet exceeds 1400°C), attempts to optimize the parameters upstream of the steam turbine encounter certain difficulties due to the fact that in increasing steam parameters, in particular, in case of significantly increased pressure from 12.0 to 27.0 MPa with unmatched increase of temperature from 565 to 580°C, a growth of moisture content in the turbine last stages will take place. This generates the need to use steam reheating with the corresponding increase of turbine unit cost.

Increasing steam parameters to ultrasupercritical conditions (27.0 MPa, 580°C) allows the CCP efficiency to be increased to 56%; however, this entails a growth in the specific cost of the installation (per unit power capacity) due to a higher cost of equipment and pipelines that have to be made of expensive grades of steel. Development of new turbine structural materials having the required service properties for operation under ultrasupercritical steam conditions is the main problem in making the new level of parameters an industry standard [7]. The use of steel having an increased strength and heat resistance results in that the cost of equipment and pipelines increases by a factor of 2–3. Increasing steam pressure generates the need to use thicker and, hence, heavier parts. In turn, this leads to a growth of stresses in them, due to which the turbine becomes less maneuverable, reliable, and amenable for repair.

Despite certain improvement in technical–economic indicators and turbine power output as a consequence of increasing the parameters, operation at ultrasupercritical parameters results in degraded reliability of the equipment. When such a turbine works out its fleet service life, it will be necessary to replace a large amount of expensive components: high-pressure circuit and reheat steam pipelines, valve units, high-pressure rotors and casings, and other parts, which will lead to unjustified costs.

The payback period of the turbine for a CCP operating at ultrasupercritical parameters in European countries is 15–17 years, whereas in Russia it can reach 20 years. Thus, the payback period of such turbine approaches its service life, which makes the CCP operation economically unprofitable.

The table gives the main indicators of CCP power units for supercritical and ultrasupercritical parameters according to the UTZ data.

Thus, in selecting the optimal values of steam parameters, it is necessary to carry out a mandatory technical–economic substantiation taking into consideration high efficiency of the turbine unit and not only the project implementation cost, but also the cost of power plant operation throughout its entire lifecycle. Such problems were considered in the literature many times in connection with shifting the steam turbines of steam power units to operate at a higher stage of initial steam parameters. For example, in [8] it is pointed out that the work on optimizing the steam parameters of large cogeneration turbines should be commenced with returning from the steam pressure and temperature equal to 23.5 MPa and 540/540°C to the levels 23.5 MPa and 560/565°C. At present, UTZ specialists are elaborating the project for modernizing the series of large cogeneration steam turbines T-250/300-23.5, in which it is planned to achieve better thermal efficiency, also by means of increasing the initial and reheat steam parameters without using expensive grades of steel. This will make it possible to increase the power unit efficiency by 5% due to steam turbine improvement and by 2% due to improvement of boiler equipment. As a result, it will be possible to increase the turbine unit economic efficiency by 1.3 and 1.0% in the condensing and cogeneration modes, respectively, owing to a growth of its thermodynamic efficiency.

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Translated by V. Filatov