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RESULTS OF THE COMMERCIAL INTRODUCTION OF HONEYCOMB SHROUD SEALS ON 300 MW TURBINE UNITS

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The results of introducing honeycomb shroud seals on type K-300-240 turbine units are discussed. Design solutions for equipping the flow-through sections of the high pressure cylinders of these turbines with honeycomb shroud seals are reported. The operational efficiency of honeycomb seals is analyzed on the basis of thermal tests conducted during an operating period between repairs. Practical examples are given of the operation of the K-300-240 turbine unit with honeycomb shroud seals installed in its high pressure cylinder.

Keywords: honeycomb shroud seals, high pressure cylinder, flow-through section, radial gaps, steam turbine, modernization, thermal tests, relative internal efficiency.

Honeycomb shroud seals were installed for the first time in Russia on type K-300-240 turbine units manufactured by the Leningrad Metals Factory in unit No. 4 of the Kashira state regional electric power plant (Kashira GRÉS) and unit No. 6 of the Cherepet' state regional electric power plant (Cherepetskaya GRÉS) during major overhaul in 2004. It was decided to install them after several years of successful operation on type PT-60/75-130/13, T-100-130, and R-40-130 turbines at power plants of JSC "Bashkirénergo" and JSC "Mosénergo" [1 – 3].

These K-300-240 turbines had differently designed flow-through sections of the high pressure cylinder [4], so the technical solutions for equipping them with honeycomb shroud seals were also different.

The design shown in Fig. 1, which had been tested on PT-60 and T-100 turbines, was chosen as the basis for the turbine unit at the Cherepet' plant and a newly developed design, shown in Fig. 2, was used for the turbine unit at the Kashira plant.

In the first case, the reworking of the flow-through section included the following operations:

— machining the baffle plates of the HPC diaphragms;

— placing honeycomb inserts and then fastening them with dowels;

— welding (remaking) the rotor lugs;

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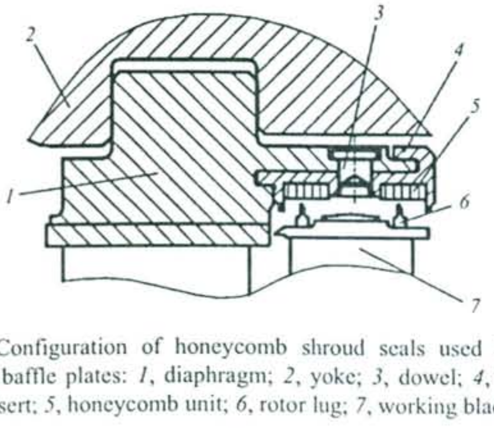

Fig. 1. Configuration of honeycomb shroud seals used in diaphragm baffle plates: *1*, diaphragm; *2*, yoke; *3*, dowel; *4*, honeycomb insert; *5*, honeycomb unit; *6*, rotor lug; *7*, working blade.

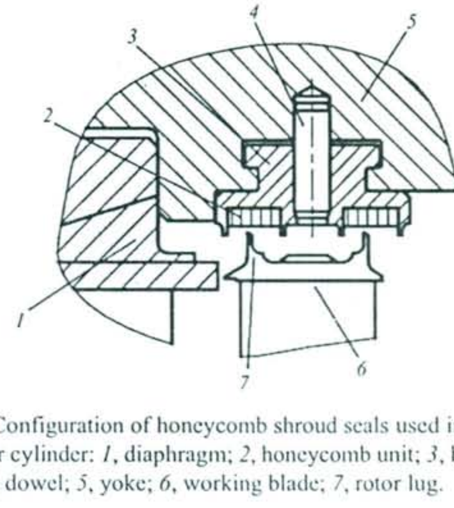

Fig. 2. Configuration of honeycomb shroud seals used in the yokes and inner cylinder: *1*, diaphragm; *2*, honeycomb unit; *3*, honeycomb insert; *4*, dowel; *5*, yoke; *6*, working blade; *7*, rotor lug.

— machine finishing of the diaphragms with honeycomb inserts to the final dimensions; and,

— test assembly of the flow-through section.

In the second case, the reworking involved the same operations, except that the inner high pressure cylinder and the diaphragm yokes were remachined. Figures 3 and 4 illustrate the machining operations on a vertical lathe performed on the inner cylinder of the HPC and diaphragm yokes at the Central repair and mechanical factory of JSC "Mosénergo" during 2004.

Honeycomb shroud seals were installed on HPC stages 3 through 12 of both turbine units.

From the time the honeycomb shroud seals were installed on it, the K-300-240 at unit No. 4 of the Kashira plant had a complicated load schedule and was actually operated in a "daytime maximum – nighttime minimum" regime, as shown in Fig. 5 (a sample for June 2006). Over the entire five year operating period, no deviations from the standards and specifications of the technical operating rules [5] were noticed.

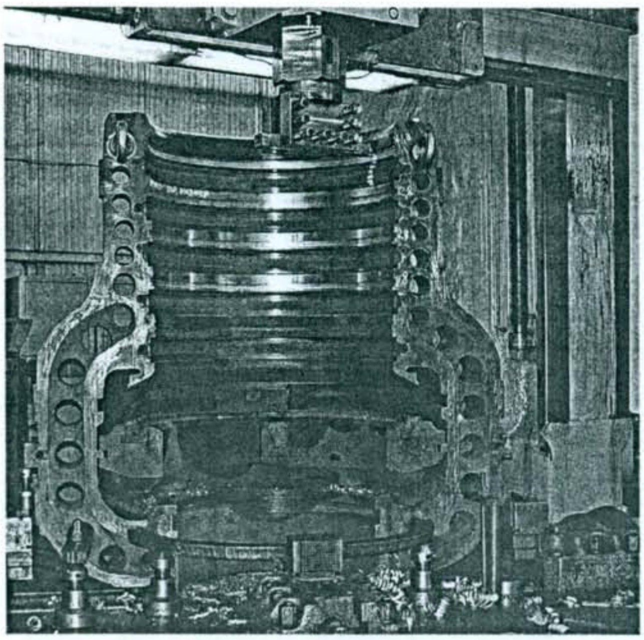

Fig. 3. Remachining the inner cylinder of the HPC.

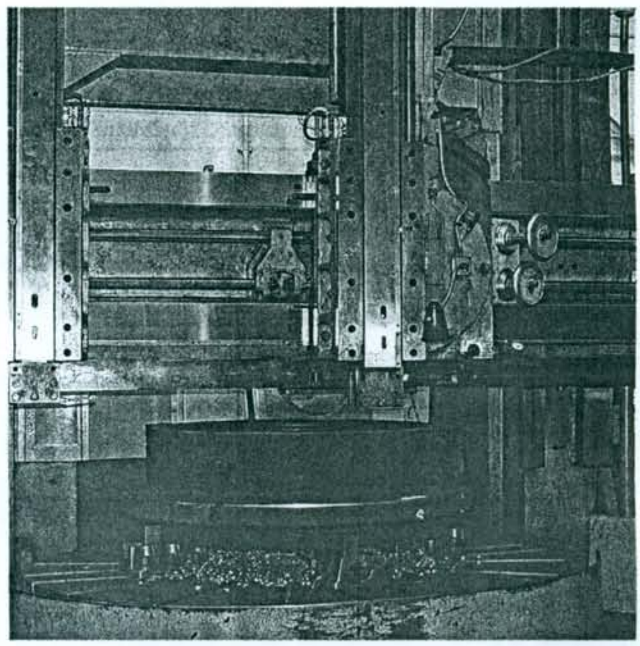

Fig. 4. Remachining the diaphragm yoke of the HPC.

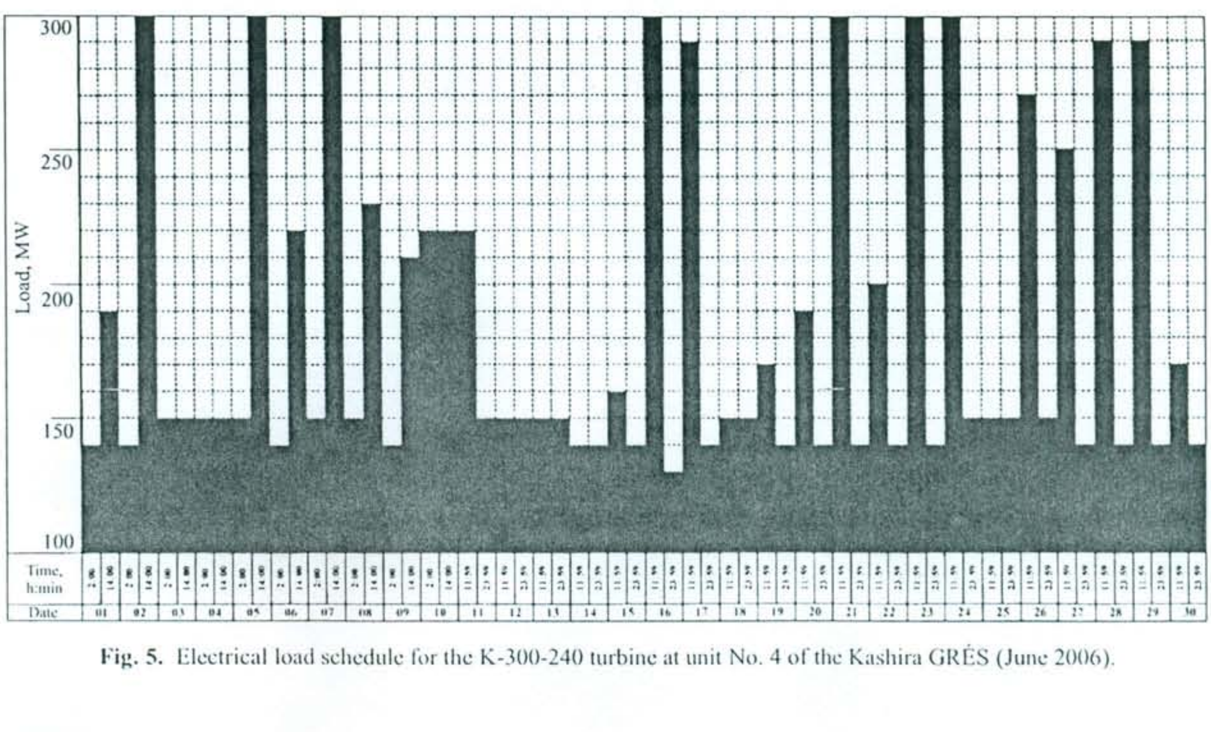

Fig. 5. Electrical load schedule for the K-300-240 turbine at unit No. 4 of the Kashira GRÉS (June 2006).

Table 1 lists statistical data on the variation in the vibrational velocity at the bearings of the turbine unit corresponding to the load variation schedule shown in Fig. 5.

The state of the turbine HPC before and after the major overhaul can be evaluated from the gap log books and the work reports of the repair company. It was noted that no additional work, beyond installing the honeycomb shroud seals, was done that might have affected the efficiency of the HPC.

Radial gaps prescribed for installing the honeycomb seals were an average of 3 mm smaller than those used for traditional axial-radial seals.

Ultimately, the reduced radial gaps led to a higher efficiency for the HPC without any reduction in its operational reliability and safety. This experience of using honeycomb seals with prescribed minimal radial gaps has subsequently been used in modernizing K-300 turbine units, including those with reactive blading.

During 2005 – 2009, units No. 3 (HPC and MPC) and No. 2 (MPC only) at the Kashira plant were modernized by installing honeycomb seals in stages 2 through 12 in the HPC and stages 14 through 16 in the MPC, as were the high pressure cylinders of units No. 2, 7, and 1 at the Iriklinskaya GRÉS (OGK-1) with installation of honeycomb seals in stages 2 through 12.

Based on these tests and commercial experience, similar steps have been taken to modernize type K-300-240-MR turbines with reactive blading manufactured by JSC "Silovye mashiny," including at the Konakovo GRÉS (OKG-5) (three turbine units) and the Lukoml' GRÉS (in Belarus) (one turbine unit). Honeycomb seals were installed on this type of turbine from stage 2 through stage 20 of the HPC, as well as the traditionally employed axial-radial seals made of Kh6 material.

Thus, 11 K-300 steam turbines with installed honeycomb shroud seals are currently in operation in different kinds of power generating systems. In addition, during 2010 it is planned to install these seals in another two K-300-240 turbine units at the Iriklinskaya GRÉS (OGK-1).

Beyond introducing technology that ensures reliable and safe operation of a turbine, there is equal interest in evaluating the effectiveness of a unit from the standpoint of economic efficiency and the times over which it is paid for.

For the purpose of determining the efficiency of modernizing the flow-through section of the HPC with honeycomb shroud seals, as well as for evaluating the stability of its operating characteristics between repairs, experts from JSC "Firma ORGRÉS" carried out thermal tests of a K-300-240 system at unit No. 4 of the Kashira plant. The first and second stages of these tests were completed in 2004 (March – August), before and after installation of the honeycomb seals, and the third stage, in 2009 (November), after 5 years of operation. At the time of the second stages of the tests, following installation of the honeycomb shroud seals, the turbine had run for 190,443 h, and at the time of the third test, for 22,6875 h; thus, the turbine had been run with honeycomb seals for 36,432 h.

The first and second stage tests were intended for determining the one-time effect owing to replacing the axial-radial shroud seals on the HPC with honeycomb seals.

In the third stage, the stability in the relative internal efficiency of the HPC was determined after 5 years of operation by comparison with data from the second stage tests.

In the following we discuss the method and present some results from the thermal tests.

The schedules and methods for the thermal tests were coordinated with the firm JSC "Silovye mashiny."

TABLE 1. Measured Vibration State of the K-300-240 Turbine at Unit No. 4 of the Kashira Plant in 2006

Bearing	Component	Vibrational velocity, mm/sec										
		June 1	June 2	June 3	June 4	June 5	June 6	June 7	June 8	June 9	June 10	June 11
No. 1	V	1.2/1.2	1.2/1.2	1.3/1.2	1.3/1.2	1.2/1.3	1.4/1.6	1.1/1.0	1.3/1.2	1.1/1.3	1.2/1.3	1.3
	T	1.2/1.3	1.3/1.3	1.6/1.5	1.3/1.2	1.3/1.2	1.4/1.5	1.3/1.3	1.3/1.3	1.3/1.6	1.5/1.6	1.7
	A	1.8/1.9	1.8/1.8	1.8/1.8	1.7/.1.8	1.6/1.3	1.7/1.9	1.7/0.7	0.8/0.9	0.8/1.0	0.6/0.8	1.0
No. 2	V	1.4/1.7	1.5/1.3	1.1/1.2	1.5/1.5	1.5/1.6	1.4/1.8	1.6/1.7	1.3/1.3	1.4/1.5	1.5/1.5	1.7
	T	1.2/1.5	1.3/1.2	1.4/1.4	1.3/1.8	1.7/1.2	1.5/2.0	1.2/1.2	1.2/1.5	1.1/1.5	1.6/1.8	2.1
	A	1.4/1.4	1.4/1.4	1.3/1.4	1.2/1.3	1.1/0.8	1.1/1.3	1.3/1.2	1.3/1.4	1.3/0.5	0.4/0.3	0.5
No. 3	V	1.0/0.6	0.5/0.4	0.4/0.4	0.9/0.3	0.4/1.0	0.5/1.0	0.6/0.7	0.9/0.5	0.4/0.4	0.5/0.5	0.7
	T	1.1/1.1	1.2/1.2	1.2/1.2	1.2/1.0	1.2/1.0	1.4/1.2	1.2/1.4	1.3/1.1	1.4/1.2	1.3/1.1	1.1
	A	2.7/2.8	1.9/1.9	2.7/2.7	2.6/2.5	1.3/2.3	0.8/2.7	2.4/1.0	2.5/2.8	1.8/2.7	1.5/2.5	1.9
No. 4	V	2.2/2.2	1.8/2.0	2.4/2.4	1.5/2.1	1.7/1.9	1.7/1.8	2.1/1.3	1.7/2.2	2.0/2.3	1.6/2.2	2.1
	T	0.5/0.4	0.4/0.4	0.4/0.5	0.7/0.7	0.5/0.7	0.4/0.7	0.4/0.8	0.7/0.7	0.4/0.7	0.7/0.7	0.7
	A	2.9/3.1	2.2/2.2	3.0/3.0	2.8/2.8	1.6/2.5	1.3/3.0	2.8/1.3	2.8/3.1	2.2/3.0	1.7/2.7	3.0
No. 5	V	1.3/1.6	1.5/1.6	1.5/1.4	0.8/1.1	1.5/0.9	1.4/0.8	1.5/1.4	1.0/1.2	1.4/1.3	1.4/1.2	1.1
	T	0.4/0.4	0.5/0.5	0.3/0.3	0.7/0.3	0.8/0.4	1.1/0.4	0.6/0.4	0.7/0.3	0.5/0.4	0.4/0.3	0.3
	A	2.3/2.3	2.6/2.8	1.8/1.8	1.2/1.4	2.8/1.7	2.5/1.6	2.8/2.6	1.3/2.0	2.3/2.0	3.0/1.7	1.6

Notes: 1. V, T, and A are, respectively, the vertical, transverse, and axial components of the vibrational velocity. 2. The numerators give vibrational velocity at 2:00 and the denominators — at 14:00. 3. The vibrational velocities on June 11 are for 11:59.

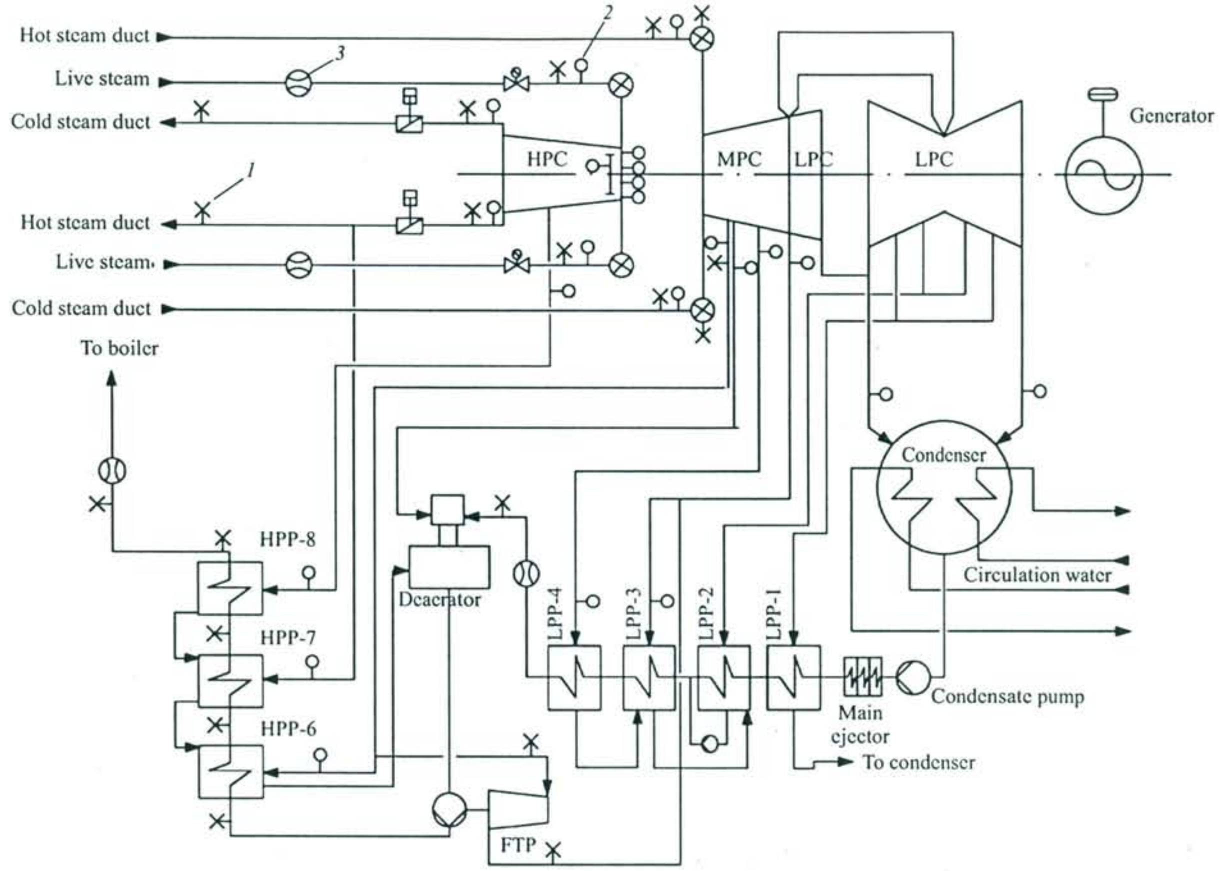

Fig. 6. Layout of the sensors for measuring the parameters of the K-300-240 turbine at unit No. 4 of the Kashira plant: *1*, *2*, *3*, measurement points for temperature, pressure, and flow rate, respectively; HPP, high-presssure preheat; LPP, low-presssure preheat; FTP, feed turbo pumps.

To minimize the errors in the final results, the tests were carried out in accordance with a unified technical program using the same measurement apparatus and the economic effect was evaluated in two independent ways:

— by comparing the electrical power of the turbine unit, and

— by comparing the spread in the values of the internal relative efficiency of the HPC in experiments with regeneration (high pressure preheat) turned off and on.

During the tests, the flow rates of live steam, feed water, and main condensate were determined using operational flow meters, whose measurement readouts had been checked with a standard calibrator from SI-Instruments. The steam pressure in the flow-through section and ahead of the regenerative preheaters was measured with class 0.6 manometers which had been checked beforehand. The temperatures used to calculate the internal efficiency of the HPC were measured by operational thermocouples which had been checked in accordance with standard specifications. The electrical load was measured using two certified OGRÉS class 0.2 wattmeters. The sensor positions and measurement points are indicated in the diagram of Fig. 6.

Nine tests were carried out in each stage; of these five were done according to the design configuration in which the high pressure preheaters were turned on and four, with the high pressure preheaters turned off. Each test lasted at least 40 min.

The internal efficiencies of the HPC were calculated using the "E3 00" computer program developed by JSC "Silovye mashiny." The method for estimating the efficiency of the rebuilt seals in the HPC was based on the established fact that, with activated regeneration, part of the high temperature seepage through the shroud seals is dumped into the corresponding preheaters and causes a drop in the steam temperature after the cylinder; thus, the calculated internal efficiency will be higher than the analogous values for tests with the regeneration turned off [6]. Hence, the difference in the temperatures after the HPC (and, therefore, the efficiency, as a function of this temperature) in tests with the high pressure preheater turned on and off will provide information on the overall amount of seepage through the shroud seals, i.e., on their efficiency.

Compared to a direct comparison of the relative efficiency of the HPC between stages, the proposed method for evaluating the efficiency of honeycomb seals has a number of important advantages. The main advantages are the following:

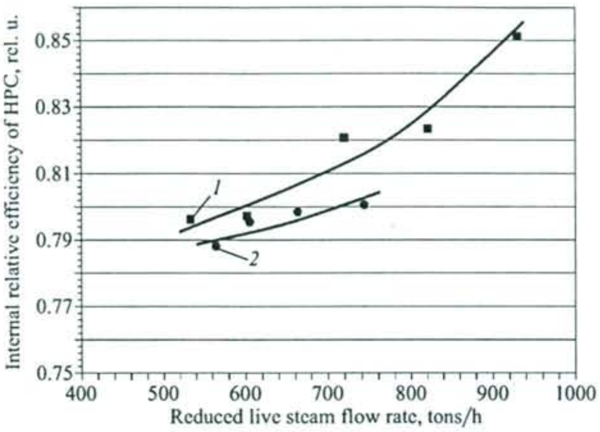

Fig. 7. Variation in the internal efficiency of the HPC of the K-300-240 turbine at unit No. 4 of the Kashira plant prior to installation of honeycomb seals (first stage of tests): *1*, *2*, operation with high pressure preheater turned on and off, respectively; the live steam flow rate is reduced to standard conditions, pressure 101.325 kPa and temperature 0°C.

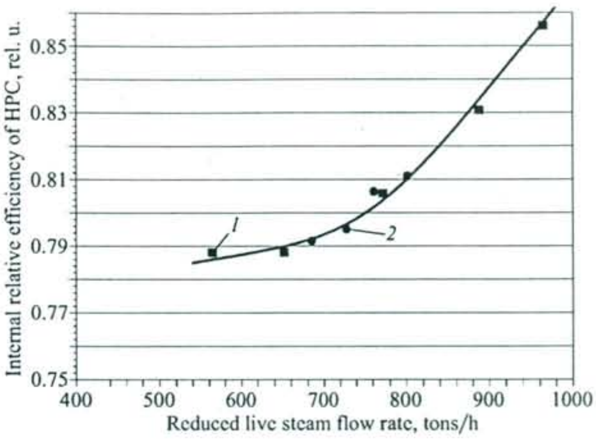

Fig. 8. Variation in the internal efficiency of the HPC of the K-300-240 turbine at unit No. 4 of the Kashira plant following installation of honeycomb seals (second stage of tests): notation as in Fig. 7.

— the influence of accumulated metrological error is essentially eliminated because the same means of measurement are used. Otherwise, their characteristics might change, both during the major overhauls and during operation between repairs. (For example, a change in the error of measuring the steam temperature after the HPC by standard measurement channels of just 1°C will lead to an increase in the error in the efficiency of the cylinder by roughly 0.5%.)

— other factors (such as salt blockage, abrasion of nozzle or blade apparatus, etc.) besides steam leakage, which might affect the efficiency of the cylinder, are eliminated.

These calculations and an analysis showed the spread in the values of the relative efficiency of the HPC in tests with the regeneration turned on and off before reconstruction (first stage) ranges from 1.0 to 1.5%, while it was close to zero in the tests after reconstruction (second stage) (Figs. 7 and 8).

Therefore, it has been shown convincingly that installing honeycomb seals does reduce the seepage of steam in the shroud seals of the HPC.

The third stage of tests was intended to evaluate the stability of this effect. Similarly to the first two tests, the third test also relied on comparing the values of the internal relative efficiency of the HPC in experiments with regeneration turned on and off. The turbine unit operating conditions in the first two stages were fully repeated during the third test stage.

An analysis of the results of the third stage and a comparison of these with the earlier results show that there is essentially no spread in the values of the relative internal efficiency of the HPC in the experiments with the high pressure preheater turned on and off; thus, the total leakage through the shroud seals was essentially the same, which confirms the stability of the characteristics of the honeycomb shroud seals over the five years between repairs (Fig. 9).

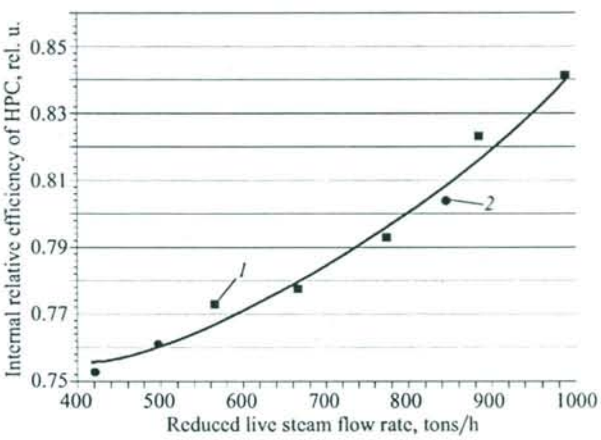

Fig. 9. Variation in the internal efficiency of the HPC of the K-300-240 turbine at unit No. 4 of the Kashira plant with honeycomb seals after 5 years of operation (third stage of tests): notation as in Fig. 7.

A slight reduction in the efficiency of the HPC by 1.5 – 2% was observed during the period between repairs. The reasons for this might be, for example, salt blockage of the flow-through part or other circumstances, but not an increase in the seepage through the honeycomb shroud seals.

An analysis of the economic performance of the turbine by specialists at the Kashira plant showed that the annual economic effect of their introduction since 2005 (turbine run for 5958 h, $N_{avg} = 217$ MW) was 5 million rubles and the time over which the installation of the honeycomb shroud seals pays for itself is 8 – 10 months.

CONCLUSIONS

1. Installing honeycomb shroud seals in the HPC of supercritical steam turbine units

— increases the relative internal efficiency of the cylinder by 1 – 1.5%, which is equivalent to increasing the power by 1 – 1.2 MW under nominal operation;

— ensures operation in accordance with the standards specifications in the technical operating rules, including those regarding vibrational state;

— provides stable performance of the flow-through part in terms of minimizing shroud seepage during the time between repairs, or at least 5 years of running the turbine unit; and,

— is an energy efficient, low cost measure that can repay the cost of its installation on a K-300 turbine within 10 – 12 months.

2. Positive experience with the operation of honeycomb shroud seals on K-300-240 supercritical steam turbines serves to recommend their installation on T-250/300-240 turbines, as well as on type K-500 and K-800 steam turbines.

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