EXPERIENCE WITH THE INTRODUCTION OF HONEYCOMB SEALS IN STEAM TURBINES

S. V. Ushinin[1]

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Experience with the introduction of honeycomb seals in the flow-through sections of 60 – 660 MW steam turbines is examined. The structural features of the design and installation of honeycomb shroud and end seals are discussed. A checklist is set up for the work required to modify the high and low pressure cylinder flow-through sections for installing seals of these types. Practical examples of the operation of honeycomb seals in the flow-through sections of operating steam turbines are presented.

Keywords: honeycomb shroud and end seals, steam turbines, yoke, diaphragm baffle plate, modernization, flow-through section.

The use of high technology, energy efficient, but inexpensive, easily purchased engineering solutions is important, both in the creation of new designs for steam turbines and for their modernization.

One of the most promising ways is still work aimed at improving the flow-through sections of steam turbines by using honeycomb seals.

Two problems are solved simultaneously through the use of honeycomb seals:

— the economic efficiency of the flow-through section is increased; and

— the operational reliability and safety of the turbine system as a whole are increased.

The first problem is solved by the reduction in the radial gaps between the whiskers of the rotor shroud and the seal surface (honeycomb inserts), which reduces parasitic steam overflow.

[1] NPP "ARMS," Moscow, Russia.

A solution to the second problem is provided by the design of the seal surface, i.e., using honeycombs, which permit contact between the turbine rotor and stator without serious consequences for the efficiency of the turbine unit.

This is true of both the shroud and end honeycomb seals.

The efficiency of using **shroud honeycomb seals** has been demonstrated by operational experience with more than 90 turbine units with powers ranging from 25 to 300 MW equipped with this type of seals, as well as by the extensive positive results of thermal tests carried out by the firm JSC "Firma ORGRÉS" with the participation of technical staff from electric power stations.

Shroud and end honeycomb seals were first installed on steam turbines in 1994 and through 2009 have been successfully used in PT-30-90/10, T-50-130/13, R-40-130, T-100-130, R-100-130, and T-250/300-240 turbines manufactured by the firm JSC "Ural'skii turbinnyi zavod" (Yekaterinburg), R-50/60-130, PT-60-130/13, PT-80/100-130/13, T-180/210-

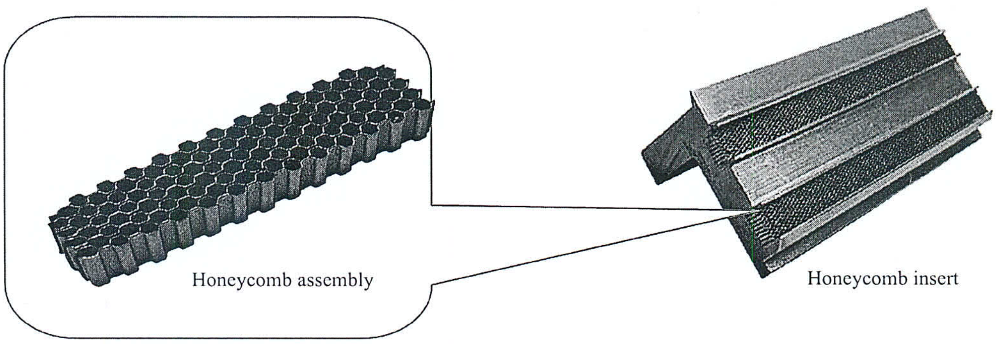

Fig. 1. External appearance of a honeycomb insert for the regulator stage of a PT-65-130/13 turbine.

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130, K-200-130, and K-300-240 manufactured by the firm JSC "Silovye mashiny" (St. Petersburg), and 3P3, TK-120, WPT-25, 13K-235, and 13UP-55 turbines manufactured by Alstom (Elblong, Poland) by various power generating systems in Russia, Belarus, Poland, and Lithuania.

Honeycomb shroud seals (Fig. 1) are made up of a set of inserts, ranging in number from 20 to 30 depending on the diameter of the surface being sealed. Each insert consists of a housing with honeycomb units attached to it by high temperature soldering. The honeycomb housing is made of heat resistant steel. The honeycomb units are made out of 0.05-mm-thick heat resistant chromium nickel foil with a hexagonal cell shape along their longitudinal cross section. The transverse height of the honeycombs is at least 4.0 – 5.0 mm and the diameter of the circle inscribed in a cell is about 1 mm.

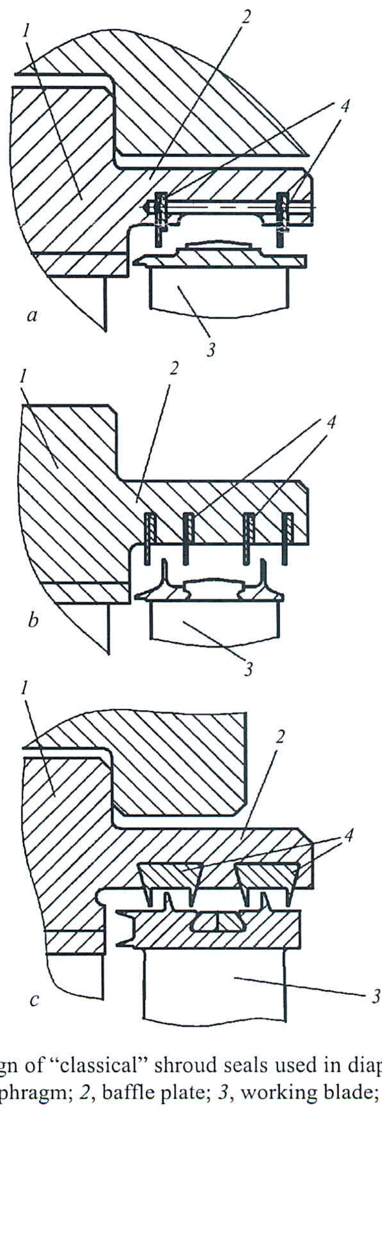

Fig. 2. Design of "classical" shroud seals used in diaphragm baffle plates: *1*, diaphragm; *2*, baffle plate; *3*, working blade; *4*, loop seals; *5*, X6 insert.

The creation of honeycomb seals for steam turbines was based on experience in the design and utilization of this type of seals in aircraft engine construction. A part of the engineering operations at the aircraft engine enterprise FGUP "NPP Motor" (Ufa) has been converted to the production of honeycomb seals for steam turbines.

The production technology for honeycomb shroud seals involves a series of successive thermal and mechanical operations. First, a flat ring of the required diameter is made from a slab and is then mechanically worked on a lathe. Then the ring is cut into segments and the honeycomb pieces are placed in them by high temperature soldering. The production cycle for fabrication of a set of honeycomb seals for a turbine lasts 3 – 4 months. Honeycomb seals with a maximum diameter of up to 2300 (in the seal zone) of up to 2300 mm can currently be produced.

The honeycomb seals are different when used for new steam turbines and when modernizing operational ones. A new layout for the flow-through sections of steam turbines generally allows the use of standardized honeycomb seals components, while special design is required for modernizing an existing turbine in order to adapt to its existing flow-through sections.

Shroud seals of the traditional design are mounted either in the baffle plates of the diaphragms or immediately in the yoke or the inner cylinder. Figures 2 and 3 show standard

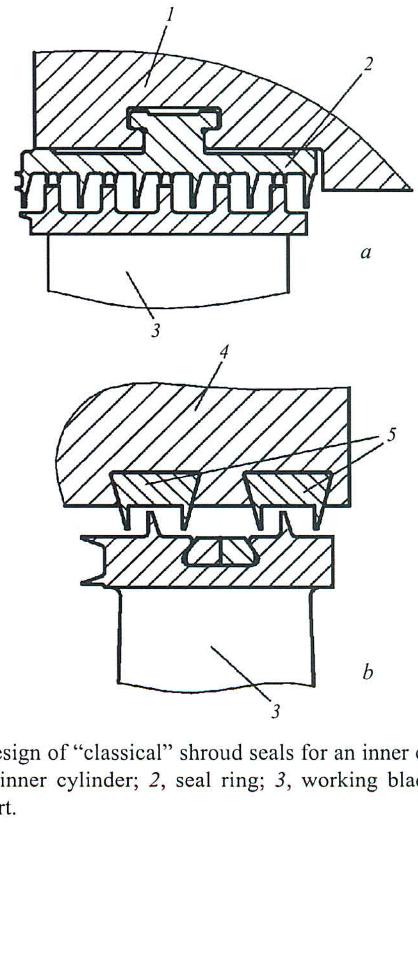

Fig. 3. Design of "classical" shroud seals for an inner cylinder and yokes: *1*, inner cylinder; *2*, seal ring; *3*, working blade; *4*, yoke; *5*, X6 insert.

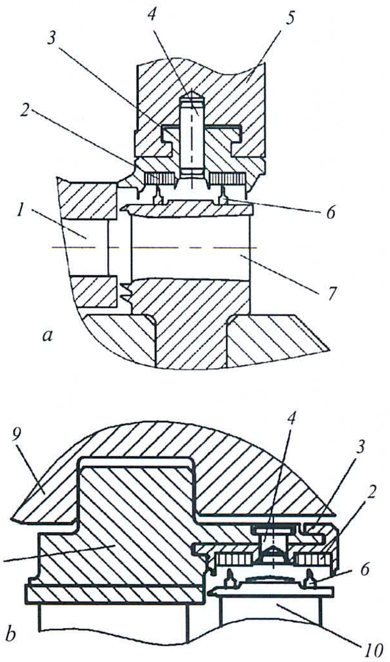

Fig. 4. Design of honeycomb shroud seals used in the yoke of the regulator stage (*a*) and in diaphragm baffle plates (*b*): *1*, nozzle; *2*, honeycomb assembly; *3*, honeycomb insert; *4*, pin; *5*, regulator stage yoke; *6*, rotor lug; *7*, regulator stage blade; *8*, diaphragm; *9*, yoke; *10*, working blade.

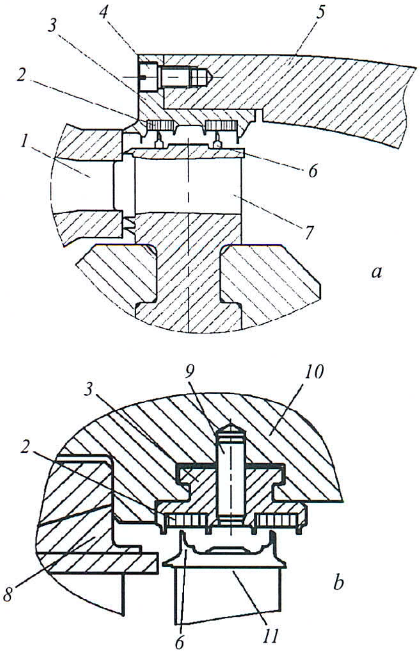

Fig. 5. Design of honeycomb shroud seals for yokes (*a*) and an inner cylinder (*b*): *1*, nozzle; *2*, honeycomb assembly; *3*, honeycomb insert; *4*, screw; *5*, yoke No. 1 for regulator stage; *6*, rotor lug; *7*, regulator stage blade; *8*, diaphragm; *9*, pin *10*, working blade.

layouts of shroud seals for steam turbines currently in operation.

The radial seal configurations shown in Fig. 2*a*, *b*, came into use in the 1960's and were defective because of a "thinning" of the flow-through section owing to their chafing against and eroding the seal "whiskers" of the turbine stator, with a loss of economic efficiency.

The axial-radial seal configuration of Figs. 2*c* and 3*b*, which has been in use since the 1980's, provides greater economy and improves the vibrational state of the turbines in supercritical steam, but still does not prevent serious damage to the flow-through section with serious radial chafing.

Figures 4 and 5 show the shroud honeycomb seal layout employed in steam turbines from the firm JSC "Silovye mashiny" during modernization of installed equipment:

— regulator stage of type PT-60-130, and T-50-130 turbines (Fig. 4*a*);

— diaphragms of the flow-through parts of the high pressure cylinder of steam turbines of type PT-60-130, PT-80-130, and K-200-130 (Fig. 4*b*). Honeycomb seals of this design have also been installed in stages 14 to 18 of the medium pressure cylinder of type T-180-130 and K-200-130 turbine units;

— regulator stage yoke of type PT-65-130 and K-200-130 turbines (Fig. 5*a*); and,

— inner cylinder and yokes of R-50-130 and K-300-240 turbines (Fig. 5*b*).

During modernization of the flow-through parts with installation of honeycomb shroud seals the following operations are carried out:

— repair (melt, weld with subsequent machining) of flanges on the shrouds of the rotor stages (i.e., reconditioning or installing flanges) based on defectoscopy of the rotor;

— mechanical working of the stator components of the turbine during installation of honeycomb seals;

— installation of honeycomb inserts on finished parts of the turbine rotor;

— boring the working surface of the installed honeycomb inserts to their final size in accordance with design specification documents; and,

— control assembly of the flow-through section.

Thus, the honeycomb shroud seals are installed in the stages of a steam turbine where shroud seats exist over the blades, primarily the high pressure cylinder, as well as some stages of the medium pressure cylinder.

The time to complete the installation of the honeycomb shroud seals in the high pressure cylinder under the conditions of a power plant repair enterprise is no more than a month and a half, comparable to the time for a standard major overhaul of a steam turbine.

In the case where honeycomb seals are to be installed in the flow-through part of new turbines, the only necessary operations are those involved in installing the honeycomb inserts in the completely machined (machinist operations), with subsequent finishing work on their surface, honeycombs.

The layout of this type of seal, used in type K-225-130 and K-660-130 turbine units, is shown in Fig. 5*b* and, in terms of its geometrical parameters, is identical to the honeycomb seals used in modernizing K-300-240 turbines.

An analysis of data from thermal tests of the assemblies after installation of honeycomb shroud seals in the flow-through parts of modernized turbines at the firm JSC "Bashkirénergo" from 1995 to 2004 and at JSC "Taténergo" from 2003 to 2007, shows that the difference in the internal efficiencies of the high pressure cylinders of turbines with honeycomb shroud seals and turbines equipped with radial-type seals can reach 4 – 5% after a running time of 30,000 h (the time between repairs) [1].

It should also be noted that, because of the reduction in the radial gaps, the increase in the relative internal efficiency of the cylinder can be no less than 1.0 – 2.0% of the standard value.

One important advantage of the honeycomb seal layout, besides a reduction in seepage at the sealed components, is that they operate reliably, both under partial radial chafing, and when flash or other extraneous material enters the flow-through segment of the turbine.

One example of such reliable operation is the startup of a PT-60-130 turbine after major repairs in 2006. Following several unsuccessful attempts at startup, accompanied by enhanced vibrations and, as a consequence, multiple chafing in the flow-through part of the turbine, it was decided to open up the high pressure cylinder and the medium-low pressure cylinder.

Inspection revealed the presence of oil in the axial channel of the high pressure rotor and the entry into the flow-through section of many pieces of flash and other extraneous substances from the steam inlet which had damaged the surfaces of the honeycombs, as well those of the working and director blades. It was noticed that all the sealed whiskers in the shrouds of the working blades of the high pressure rotor were still intact, but traces of wear were seen on the honeycombs owing to the enhanced vibration. Damage to the honeycomb surface with embedding of large fragments of extraneous material was observed only in the honeycomb assemblies in the ninth stage of the high pressure cylinder (Fig. 6). After some of the most damaged honeycomb assemblies in this stage of the high pressure cylinder were replaced with new ones, the turbine was successfully brought into operation.

The considerable positive experience gained in running 60 – 300 MW steam turbines with modernized flow-through sections using honeycomb seals has facilitated the widespread introduction of this type of seal in the flow-through sections of the high and medium pressure cylinders of newly designed turbines. In recent years the firm NPP "ARMS," together with the NPP "Motor" has designed and installed sets of honeycomb shroud seals on steam turbines manufactured by the JSC "Silovye mashiny": K-255-130 at the Kharanorskaya and Chereptskaya GRÉS plants, T-185/210-6R at the Yuvaskyla thermal power plant in Finland, and K-660-24.7 at the Barkh and Sipat thermal power plants in India.

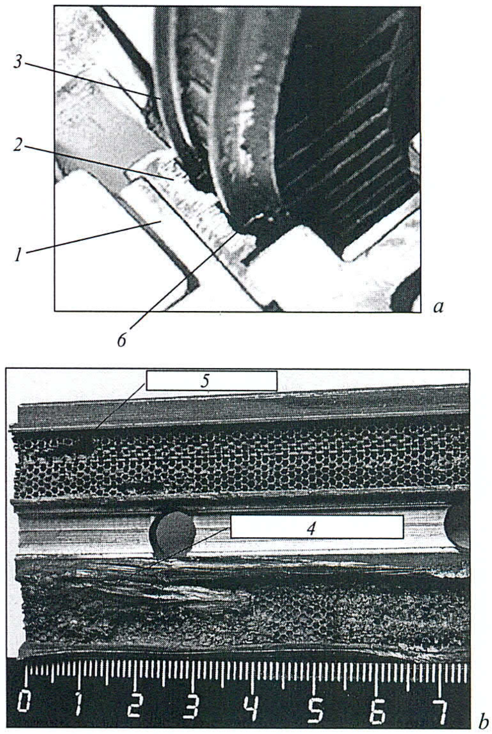

Fig. 6. Wear in honeycombs in the ninth stage of the high pressure cylinder from an accidental startup of a type PT-60-130 turbine: *1*, diaphragm baffle plate; *2*, honeycomb seal; *3*, rotor lug; *4*, fragment of a large piece of extraneous material; pressed into the honeycomb insert; *5*, scoring from impact of extraneous material; *6*, wear of the honeycomb seal.

In addition, honeycomb shroud seals have been widely used in modernizing the flow-through sections of steam turbines manufactured by JSC "Silovye mashiny," in particular the high pressure cylinders of the K-300-240 turbines at the Lukoml'skaya GRÉS plant (Belarus') and the Konakovo GRÉS plant (OGK-5). Honeycomb shroud seals are under development for modernizing the high pressure cylinders of the K-800-130 steam turbines at the Beloyarskaya nuclear power plant, K-330-240-R at the Cherepovets GRÉS plant, and K-1200-6.8/50 at the Novovoronezhskaya nuclear power plant and the Leningrad AÉS-2 nuclear power plant.

An equally important step in the modernization of the seals for steam turbines is the use of **honeycomb end seals**. Designs for traditional end seals are shown in Fig. 7.

Replacing existing end radial seals with honeycomb seals helps avoid such defects as the chipping off of the "whiskers" during axis displacements of turbine rotors, reduces oil flooding, enhances the maneuverability of the turbine unit, reduces air suction into the vacuum system, and lowers the rate of flow of steam into the end seals of the turbine. This raises the operational reliability, economy, and

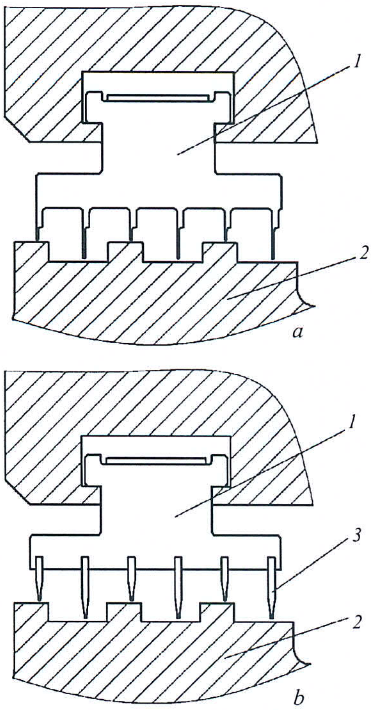

Fig. 7. Design of "classical" end seals for steam turbines: *1*, a segment of the end seal; *2*, rotor shaft; *3*, insert lugs.

lifetime of the seals, while lowering the costs of subsequent major repairs.

Honeycomb end seals are made the same way as shroud seals, but they differ in geometric size and in the number of segments in the seal ring. The maximum diameter of the ring over the seal surface is roughly 780 mm, the number of segments may vary from four to six, and the diameter of the circle inscribed in a honeycomb cell ranges from 1 to 5 mm, while the height of the cells is kept at 4 – 5 mm.

Figure 8*a*, *b* illustrate the configurations of honeycomb end seals for the medium and high pressure cylinders installed on type R-50-130, PT-60-130, T-100-130, and T-250-240 turbines, and Fig. 8*c*, those for the low pressure cylinder of the T-180-130 turbine.

The main design difference between the honeycomb end seals and the traditional seals is the presence of honeycombs on the sealed surface of the rings instead of "whiskers." while the other geometrical parameters (combined dimensions) are entirely identical. This makes it possible to reduce the material and time spent in replacing the traditional seals with honeycomb end seals.

Modernizing the turbines and installing honeycomb end seals involve the following tasks:

— machining the sealed surface of the rotor in the places where honeycomb end seals are to be installed; and

— fitting and installing the segments with honeycomb inserts at the site of the standard end seals taking centering into account (the mount of work corresponds to repair of standard end seals with replacement of 100% of the segments).

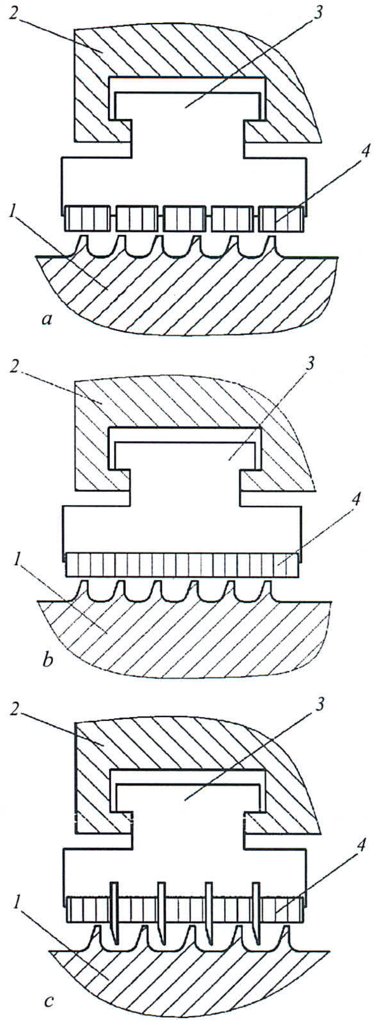

Fig. 8. Design of honeycomb end seals for steam turbines: *1*, rotor shaft; *2*, yoke; *3*, segment of honeycomb end seal; *4*, honeycomb assembly.

In the process of equipping turbines with honeycomb end seals it is assumed that the rotor will be remachined, with removal of a surface layer of the metal and the shaping of fluted bores. The accumulated thermal fatigue stresses are removed by this operation.

Honeycomb end seals have been extensively used on the above mentioned types of turbines at the firms JSC "Bashkirénergo," JSC "Taténergo," and JSC "Mosénergo."

According to the firm JSC "VTI" [2, 3], operating experience at JSC "Mosénergo" has shown that for most T-250/300-240 turbines in steady state operation, greater contraction of the medium pressure rotor RSD-2 is observed, reaching the "red line" (–4.5) in some turbines. Introducing a cooling system for RSD-1 and a metal-teflon ribbon aggravates this problem. During transient operation, especially load shedding, axial chafing is possible which may cause misalignment of the rotor of the medium pressure cylinder TsSD-2. In order to eradicate this defect it was best to install honeycomb seals on all five seal rings with the corresponding machining of the rotor.

Honeycomb seals have been introduced in end seals at a number of "Mosénergo" plants, including at the TÉTs-23 heating and electric power plant. Tests on a turbine showed the operation of the ejectors was improved, oil flooding was reduced, and the vacuum tightness increased by introducing these seals. It may be assumed that the pressure in the condenser was reduced by 0.005 kgf/cm^2. This leads to an increase of 0.17% in the efficiency for the unit. Given that the unit operates in the condenser mode for no more than half a year, the efficiency increase for the unit is 0.08% [2, 3].

The reliability and high service lifetime indicators of honeycomb end seals can be illustrated by excerpts from an inspection report on honeycomb seals for the medium pressure cylinder TsSD-2 (T-250/300-240 unit of plant TG-4 at Mosénergo's TÉTs-26): "the radial wear on the honeycombs is from 0.5 to 0.8 mm, and the axial wear, up to 3.5 mm. The flanges of the inserts for the medium pressure rotor RSD-2 are in a good state, with no visible traces of wear or heating. The overall state of the honeycomb seals is satisfactory, with repair or replacement not needed." At this point the turbine had been run for 40,406 h since the time honeycomb end seals were installed on it in 2003.

The considerable practical experience accumulated by power plant repair companies shows that reworking the rotor and stator of a steam turbine during installation of honeycomb seals entails no serious engineering problems and can be carried out under the power plant repair conditions within the time scales of typical major repairs for a turbine, i.e., roughly 30 – 44 days.

This work has been done by the firm TsRMZ, a branch of Mosénergo during modernization of K-300-240 units at the Kashira GRÉS (OGK-1) plant, and T-250-240 units at TÉTs-23, -25, and -26 (JSC Mosénergo); by "KamÉnergo-Remont" a branch of JSC "Taténergo" during modernization of type T-100(110)-130, R-40-130, and PT-60-90(13) turbines for the Nizhekamsk TÉTs (heating and electric power plant), Naberezhnyye Chelny TÉTs, and the Kazan' TÉTs-3 plant; and by JSC "Uralénergoremont" during modernization of K-300-240 class turbines for the Iriklinksaya GRÉS (OGK-1) plant.

Thus, the operational reliability and practical confirmation of the efficiency of using honeycomb shroud and end seals means that this type of seal can be recommended for extensive commercial introduction.

One of the important problems in the construction of steam turbine equipment is standardizing the designs of the individual components and elements, in order to reduce the cost of fabricating and using them.

Thus, there is an understandable need to creating a standardized design for honeycomb shroud seals which could be used in any type of turbine. Honeycomb seals of this design should satisfy the following criteria:

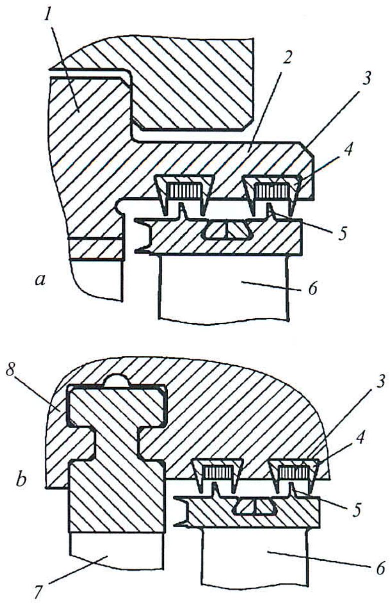

Fig. 9. Design of standardized honeycomb shroud seals for diaphragm baffle plates (*a*), and for the yokes and inner cylinder (*b*): *1*, diaphragm; *2*, diaphragm baffle plate; *3*, honeycomb assembly; *4*, honeycomb insert; *5*, rotor lug; *6*, working blade; *7*, director blade; *8*, yoke.

— be standardized for installation in any steam turbine;

— be easily repaired, without the use of special machines or equipment; and,

— be installable without significant remachining of the flow-through section, especially the stator.

The fabrication of honeycomb seals that meet these specifications will reduce the overall cost of the set of honeycomb seals and ensure a secure supply of honeycomb inserts that can be installed in any stage of any type of turbine.

The scientific and manufacturing firm "ARMS" and SKB "Turbina" of the Leningrad Metals Plant, a branch of JSC "Silovye mashiny," are jointly working in this area.

Figure 9 shows the design of a honeycomb insert which meets the above specifications. In terms of its geometric parameters, this standardized insert is fully identical to the U-shaped axial-radial inserts made of X6 material, can be installed both in diaphragm baffle plates (Fig. 9*a*) and in the yoke or inner cylinder (Fig. 9*b*); hence, it can be used in essentially all 60 – 800 MW turbines, which are being modernized or newly designed.

In terms of engineering, the installation of honeycomb seals is uncomplicated and entirely the same as installing U-shaped X6 inserts in the inner cylinder or yoke.

When installing these inserts in the diaphragm baffle plates in place of lobed seals, the following mechanical operations must be performed:

— to minimize thermal deformation, arrange for weld smelting, thermal processing, and mechanical reworking of the two halves of the diaphragm simultaneously, with the mutual position of the upper and lower halves set in special jigs;

— after final mechanical finishing, ensure that the gaps at the joints between the upper and lower halves specified in the assembly drawings are satisfied. When necessary, smelting of the joints is allowed in accordance with repair technologies followed by mechanical refinishing; and,

— at the same time as the smelting of the end section, weld the apertures under the caulking of the seal and support plates in order to improve the fixing of the honeycomb seals in the baffle plates.

At present, as part of the joint program of the Leningrad Metals Plant (LMZ), a branch of JSC "Silovye mashiny," and the NPP "ARMS," a test batch of honeycomb inserts with the above standardized design has been manufactured and technical operations are being developed for mounting them in the flow-through section of an experimental yoke.

That work will contribute to the development of routine engineering plans which will make it possible to install honeycomb inserts in the flow-through section of steam turbines, whether they are newly designed under factory conditions or being modernized in power plants or repair facilities.

CONCLUSIONS

1. Honeycomb seals can be used to maintain minimal shroud leakage over a longer period of time than other types of seals

2. Honeycomb seals can prevent wear of the seal whiskers in the shrouds of the working blades under nonstandard conditions (significant radial and axial chafing in the shroud seals, entry of flash into the flow-through section, etc.).

3. The creation of a new standardized design for honeycomb seals greatly reduces the time and cost for installing them during major repairs of turbines and does not require remachining of their flow-through sections.

4. The high reliability and efficiency of honeycomb shroud and end seals in various types of steam turbines means that they can be recommended for widespread adoption in industry.

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