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# CREATION OF OPTIMAL DESIGN OF RUNNER OIL SYSTEM OF KAPLAN HYDRO-TURBINES

[1] **Viktor H. Subotin,** office@turboatom.com.ua
ORCID: 0000-0002-2489-5836

[1] **Oleksandr S. Burakov,** burakov.a.b.s@gmail.com
ORCID: 0000-0002-3264-5300

[1] **Viktor M. Iefymenko,**
efimenko@turboatom.com.ua
ORCID: 0000-0003-2140-893X

[1] **Andrii Yu. Starchenko,** starchenkoa@ukr.net
ORCID: 0000-0001-9347-7059

[2] **Yurii M. Kovalov,** dnepr@sgem.com.ua
ORCID: 0000-0001-6425-4702

[3] **Vadym L. Rassovskyi,** uge2007@ukr.net
ORCID: 0000-0001-8600-6881

[1] JSC "Turboatom"
199, Moskovskyi ave., Kharkiv, 61037, Ukraine

[2] LLC "Dnipro-Spetsgidroenergomontage"
Office 20, 8, Ihor Sikorskyi str., Kyiv, 04112, Ukraine

[3] PJSC "Ukrhydroenergo"
Vyshgorod, Kyiv region, 07300, Ukraine

*The main objectives of the reconstruction are stated. Those are: increase of the service life of the hydro-turbines of Dnipro Cascade, enhancement of their efficiency, power, and environmental safety, extension of the power control range of the hydro-power plants, assurance of the reliability and improvement of the operating safety of their equipment and structures, meeting the environmental requirements, improvement of the quality of the generated electric power after control system rehabilitation. The article deals with and analyses the chronology of the creation of the optimal design for a vertical Kaplan hydro-unit oil piping taking into consideration the half a century operational experience and stages of hydro-turbine modernization for Dnipro-2 HPP. The experience in improvement of the hydro-unit and oil head system control design is generalized, from the unified solution to the creation of the all-new design. The methods of the oil system rod machining and preliminary control are amended. The temperature control of the automatic unit shutdown in case of heating of oil head bushes is introduced into the control system. The oil piping installation method is improved and step-by-step checking of the oil piping installation centering is introduced. As a result of implementation of a package of design and process engineering solutions, the optimal design of the oil piping of improved reliability was created. It decreased the unscheduled downtime of the units and cut expenses on their maintenance providing the cyclic recurrence recommended by the standards for the operation of the oil pressure device pumps and thus, decreased the electric power consumption for balance-of-plant needs. The objects of the implementation of the developed oil piping design are given.*

***Keywords:*** *Kaplan hydro-turbine, oil piping, oil head, runner rods, runner servomotor, self-aligning rings.*

## Introduction

The cascade of hydro-power plants, dams and reservoirs that exist on the Dnipro River in Ukraine form one of the largest hydro systems in the world. The first hydro-power plant (HPP) of the system (Dnipro-1 HPP) was built near the city of Zaporizhia in 1934, and the last one (Dnipro-2 HPP) was completed in 1980. In total, there are six dams and eight hydro-power plants with 93 hydro-units located at Dnipro River section from Kyiv to Nova Kakhovka [1].

The existing Dnipro-2 HPP consists of 8 vertical hydraulic units, first commissioned in 1974. Out of these, six turbines (Units Pl. Nos. 13–18) were supplied as propeller-type turbines, two (Units Nos. 11 and 12) – as Kaplan hydro-turbines.

Nowadays, five hydro-units have been upgraded and two existing propeller-type turbines (Units Nos. 14 and 16) are subject to reconstruction at this stage. Their reconstruction includes conversion into Kaplan hydro-turbines, i.e., they must be fitted with a mechanism for controlling the angle of deployment of the runner blades, which will achieve maximum efficiency at each operating point while maintaining combinatorial dependence and operation within guaranteed power ranges and net head.

## Problem statement

The average age of the energy infrastructure of the Dnipro Cascade is currently over 35 years. In order to guarantee safe operation, long-term reliability and generating capacity, the main facilities of the HPP must undergo significant reconstruction [2]. After the reconstruction of hydro-units, the number of unplanned downtimes will also be reduced and the costs for their maintenance will be reduced as well.

The main objectives of the reconstruction:

– increase of operational reliability and prolongation of service life of hydro-units due to replacement of worn out and obsolete units taking into account modern requirements of power system;

– increase of the turbine efficiency and power;

– replacement of obsolete measuring devices in control systems;

– increase of environmental safety;

– expansion of the turbine power control range.

***Fig. 1. Oil head of the Unit Pl. No. 16 of Dnipro-2 HPP hydro-unit***

## Oil piping

The oil piping is designed to supply oil from the oil pressure device to the runner servomotor, which adjusts the angle of deployment of the turbine blades. It consists of an oil head, rods and servomotor.

The oil piping is one of the most important units of the Kaplan hydro-turbine, both in terms of reliability of the unit operation, and in terms of ecological safety.

Given the importance of this unit, it gets special attention at all stages of creation – from project development to manufacture, testing and installation.

The oil piping includes the following elements: oil head, runner rods and runner servomotor.

The ***oil head*** (Fig. 1) is used for supply of oil under pressure from oil pressure head through the main slide valve of the speed governor in the runner servomotor cavities for the blades opening and closing, for drain of the waste oil in a drain tank of oil pressure head.

During the initial design of hydro-turbines of the Dnipro-2 HPP in the 70s of the twentieth century, all the experience of domestic engineering accumulated at that time [3] was taken into account. In particular, a classic scheme with two concentric rods and three bronze bushes was used in the design of the oil head (Fig. 2) [4].

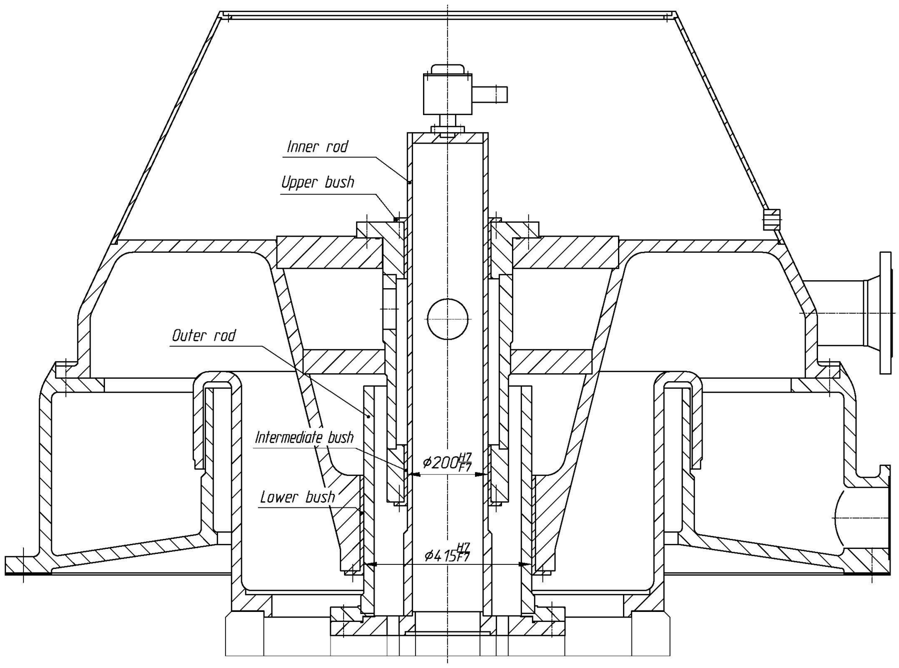


***Fig. 2. The design of the oil head with two rods and three rigid supports***

During the modernization of the units, which had been working for 30-40 years, the design of the oil head was improved taking into account the experience of operation and the emergence of new engineering and technological solutions.

In particular, a design with one rod and three bronze bushes was used at the first stage of reconstruction for Units Pl. Nos. 13 and 15 (Fig. 3). This design increased the rigidity of the oil head rods by eliminating the flange connection of the outer and inner rods, and allowed the turning of three working areas on the rod from one installation to ensure the alignment of the surfaces. A rigid three-support scheme was preserved.

During the second stage of reconstruction for Units Pl. Nos. 11, 17 and 18, a structure with one rod, middle and lower bronze bushes and one floating upper bush was designed and implemented. The upper bronze bush was replaced by a set of self-centering bronze and steel rings, which are separated by an external fitting (Fig. 4). In addition, polyurethane cuffs were installed in the upper and lower supports.

Replacement of the upper rigid support (bush) with self-aligning rings allowed to introduce the design of the oil head, which provided the transition to a two-support system. The installation of U-shaped cuffs on the oil head rod simplifies its centering and almost eliminates gaps in the support units, which significantly reduces oil flow and improves the cyclic operation of the pumps of the oil pressure device.

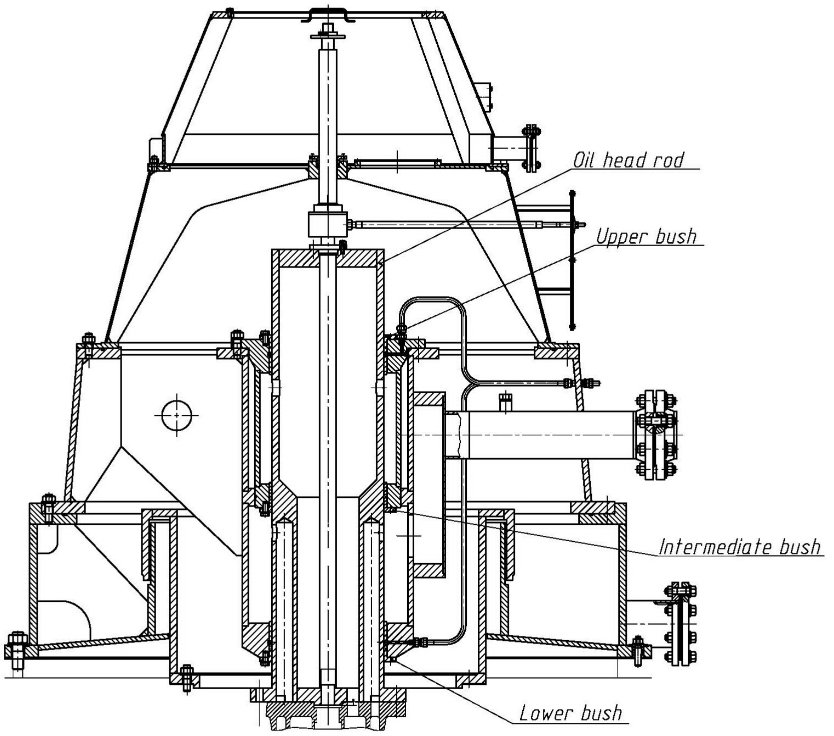


***Fig. 3. The design of the oil head with one rod and three rigid supports***

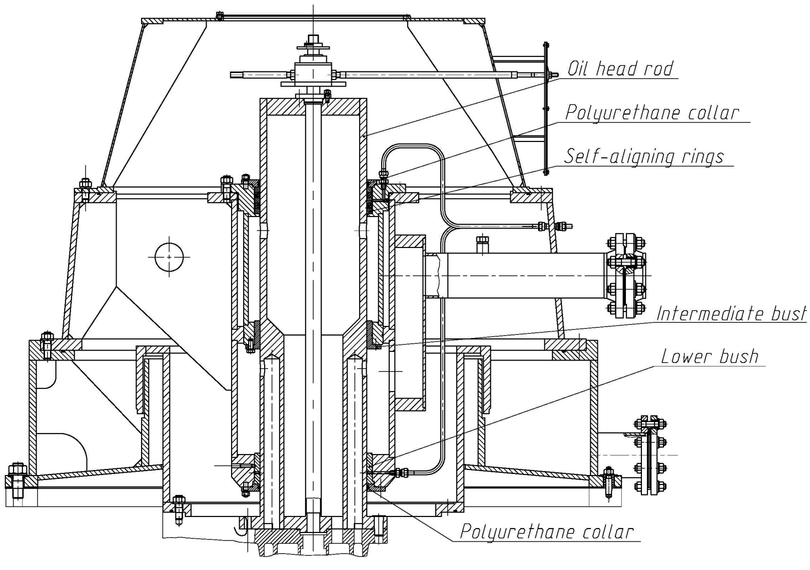


***Fig. 4. Design of the oil head with one rod, two rigid supports and one support with self-aligning bushes***

During the development of the project of reconstruction of hydro-units of Units Pl. Nos. 14 and 16, together with the specialists of PJSC "Ukrhydroenergo" and the operating personnel of the HPP, the experience of operation of the oil head structures of the previously reconstructed units was analyzed. The following solutions have been implemented in its design:

– the oil head scheme with one rod increased the rod rigidity and ensured the alignment of the rod working surfaces;

– the upper and middle supports are replaced by self-aligning rings, the lower one is made as a rigid bush, which ensured the rod centering only on the lower bush, the middle and upper ones are self-aligning;

– cuffs with oil supply are installed in the upper and lower supports for lubrication of their surfaces; this ensured the minimization of leaks and increased cyclicity of the oil pressure device pumps switching on;

– strengthening the working surface of the rod by chrome plating increased the difference in rigidity between the parts of the friction pairs;

– temperature control of bronze bushes provides automatic shutdown in case of heating;

– the use of a two-row dam prevented the overflow of oil through the oil reflector.

This design of the oil head (Fig. 5) is considered optimal during operation, and the installation organization (LLC "Dnipro-Spetsgidro-energomontage") considers it as rational for installation on site.

***Runner rods*** are installed inside the turbine shaft. Since these rods are quite long (up to 10 meters), the supporting surfaces in the upper and lower parts of the shaft are bronze. The upper rod is connected to the oil head rod and the lower rod is connected to the runner oil distributor. For convenience of manufacture, transportation and installation, the runner rods are divided lengthwise into 2 or 3 parts. Each part is welded from two concentric steel pipes of different diameters and flanges inserted axially into each other, creating two pressure cavities for the control system. The rods are connected to each other by flanges and sealed along the connector with a rubber cord (Fig. 6).

Due to the large number of flange connectors along the oil piping, the technology of parts processing by "pairs" has been introduced to ensure compliance with the requirements of

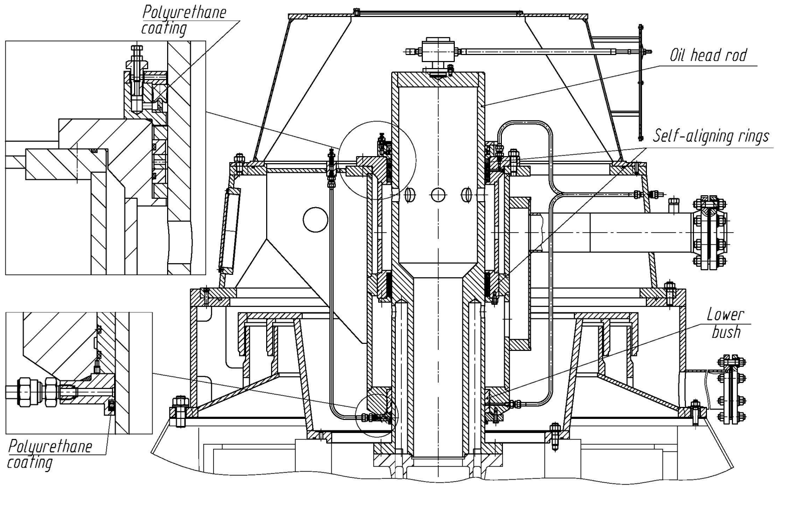


***Fig. 5. Oil head design with one rod, one rigid support and two supports with self-aligning bushes***

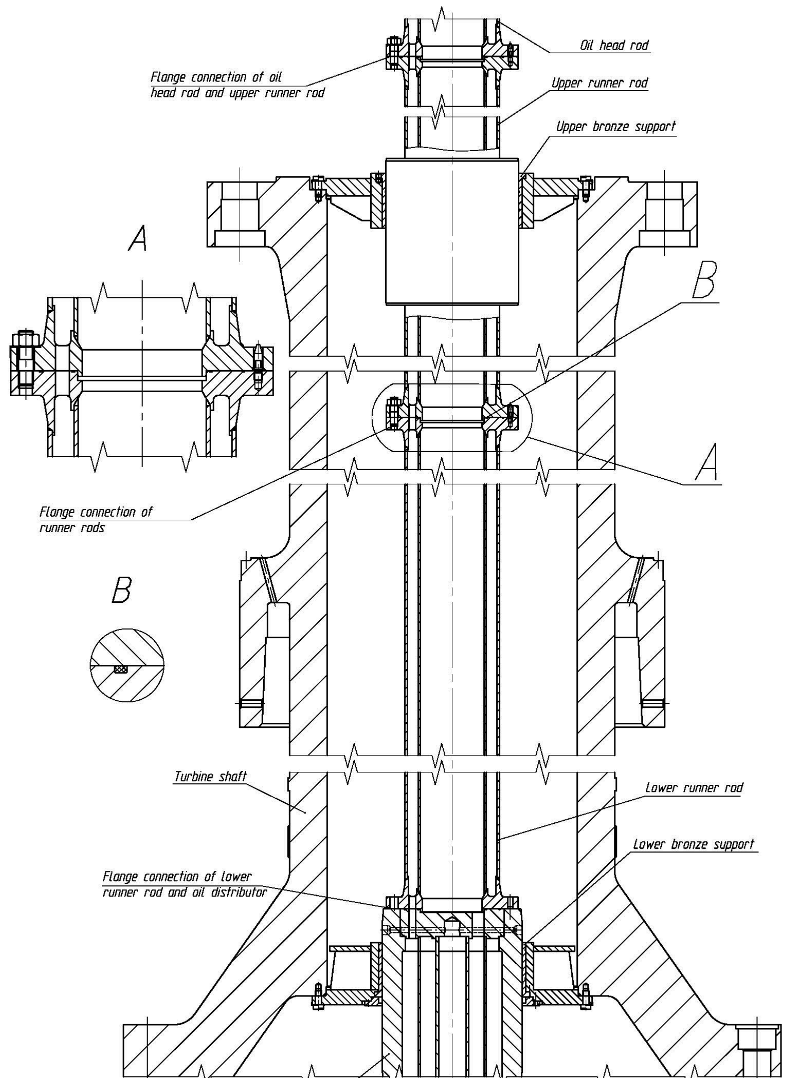


***Fig. 6. Installation of runner rods***

no fractures and minimization of beating. After the final machining of each element of the pipeline, a control connection is carried out on the lathe and for the following parts: "oil distributor – lower runner rod" and "upper runner rod – oil head". During this operation, the beating, which is eliminated if necessary, is checked.

The ***runner servomotor*** is located in the upper part of the runner hub and is closed from above by the turbine shaft flange (Fig. 7).

The runner servomotor is controlled by the existing control system.

The servomotor piston is made cast from carbon steel of the 20GSL brand. To eliminate the appearance of burrs on the servomotor piston and cylinder, the bronze overlay is made on the outer diameter of the piston. In order to prevent oil from flowing from one servomotor cavity to another, sealing elements, which ensure tight contact with the inner surface of the cylinder and uniform pressure on it, are installed on the piston.

The runner rod has a central hole to ensure the free flow of excess oil from the cavity of the runner blades rotation mechanism into the shaft cavity, and then through the drain pipe of the oil head into the drain tank of the oil pressure device control system.

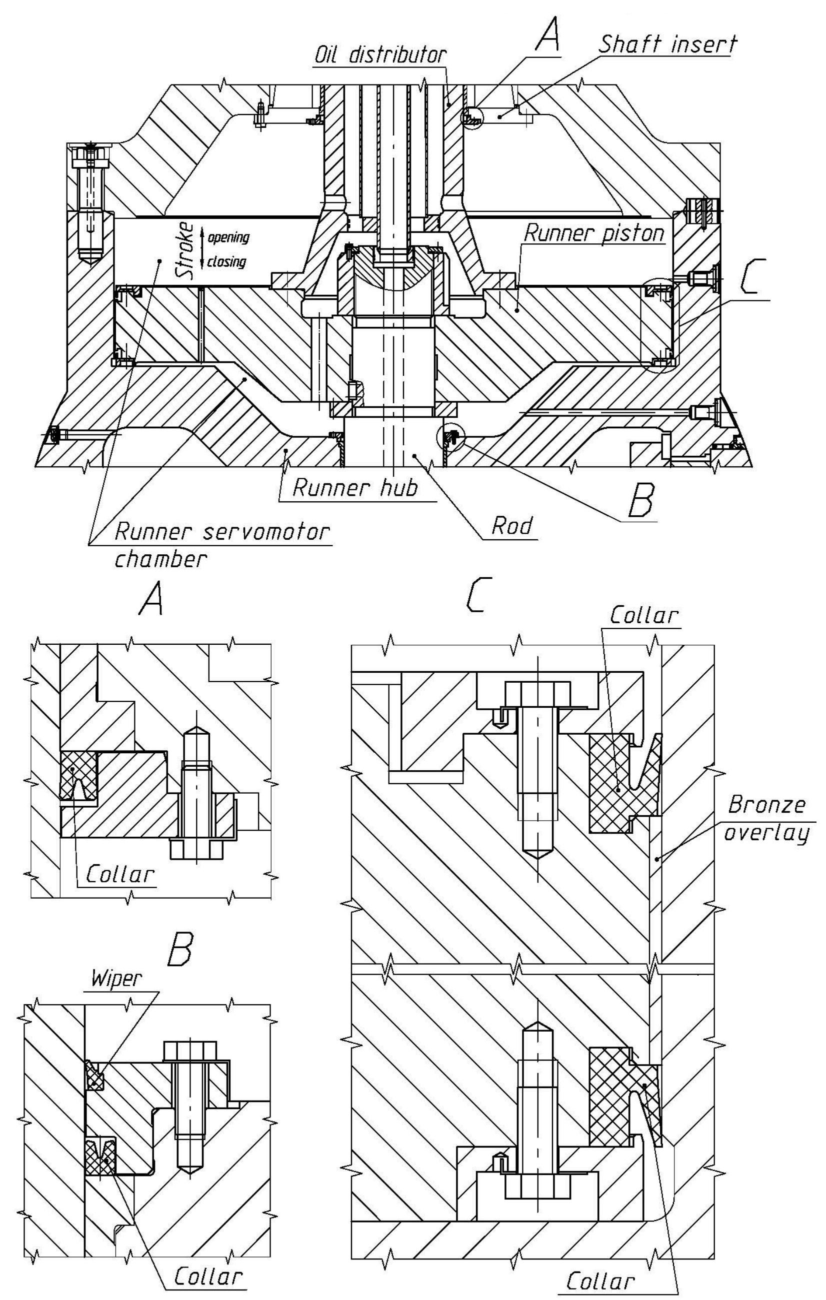


*Fig. 7. Sketch of the piston of the runner servomotor with the installed cuffs*

## Conclusions

The complex of the implemented constructive decisions on consolidation of the stock, piston, oil distributor and oil head allowed to ensure absence of overflows between servomotor cavities of the runner and oil head. Thus, it is possible to carry out the standardized cyclic operation of the pumps of the oil pressure device and, accordingly, to reduce electricity consumption for balance-of-plant needs.

The introduced technology of processing of details of the oil piping "pairs" provided achievement of design values from beating and centering of the oil head rod during installation and excluded possible breakage of rods in flange connections.

Nowadays, this design of the oil piping for vertical Kaplan hydro-turbines has been approved by the Customer (PJSC "Ukrhydroenergo") and the installation organization (LLC "Dnipro-Spetsgidroenergomontage") and implemented by JSC "Turboatom" during the reconstruction of the following hydraulic units: Units Pl. Nos. 14 and 16 of Dnipro-2 HPP, Units Pl. Nos. 4 and 5 of Kremenchuk HPP and Units Pl. Nos. 1 and 2 of the Middle Dnipro HPP.

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## Створення оптимальної конструкції маслосистеми робочого колеса поворотно-лопатевих гідротурбін


**[1] В. Г. Суботін, [1] О. С. Бураков, [1] В. М. Єфименко, [1] А. Ю. Старченко, [2] Ю. М. Ковальов, [3] В. Л. Рассовський**

[1] АТ «Турбоатом», 61037, Україна, м. Харків, пр. Московський, 199

[2] ТОВ «Дніпро-Спецгідроенергомонтаж», 04112, Україна, м. Київ, вул. Ігоря Сікорського, б. 8, оф. 20

[3] ПрАТ «Укргідроенерго», 07300, Україна, Київська обл., м. Вишгород



*Сформульовано основну мету реконструкції – збільшення терміну експлуатації гідротурбін Дніпровського каскаду, підвищення їх коефіцієнта корисної дії, потужності та екологічної безпеки, розширення діапазону регулювання потужності гідроелектростанцій, забезпечення надійності та підвищення безпеки роботи їх обладнання й споруд, виконання вимог із захисту навколишнього середовища, поліпшення якості електроенергії після реконструкції системи керування. У статті розглянуто та проаналізовано хронологію створення оптимальної конструкції маслопроводу поворотно-лопатевого вертикального гідроагрегату з урахуванням півстолітнього досвіду експлуатації та етапів модернізації гідротурбін Дніпровської ГЕС-2. Узагальнено досвід удосконалення конструкції керування гідроагрегатом та системою маслоприймача від уніфікованої до створення принципово нової конструкції. Внесено зміни в технологію механічної обробки штанг маслосистеми та попереднього контролю. У систему керування впроваджено температурний контроль автоматичного вимкнення агрегату у випадку нагріву втулок маслоприймача. Вдосконалено технологію монтажу маслопроводу та впроваджено пооперацийний контроль перевірки центрування монтажу маслопроводу. Внаслідок впровадження комплексу конструкторських і технологічних рішень створено оптимальну конструкцію маслопроводу підвищеної надійності, що зменшило кількість незапланованих простоїв агрегатів, знизило витрати на їхнє технічне обслуговування та забезпечило рекомендовану стандартами циклічність роботи насосів маслонапірної установки і, відповідно, знизило споживання електроенергії на власні потреби. Наведено об'єкти впровадження розробленої конструкції маслопроводу.*



***Ключові слова**: поворотно-лопатева гідротурбіна, маслопровід, маслоприймач, штанги робочого колеса, сервомотор робочого колеса, самоустановлювані кільця.*


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