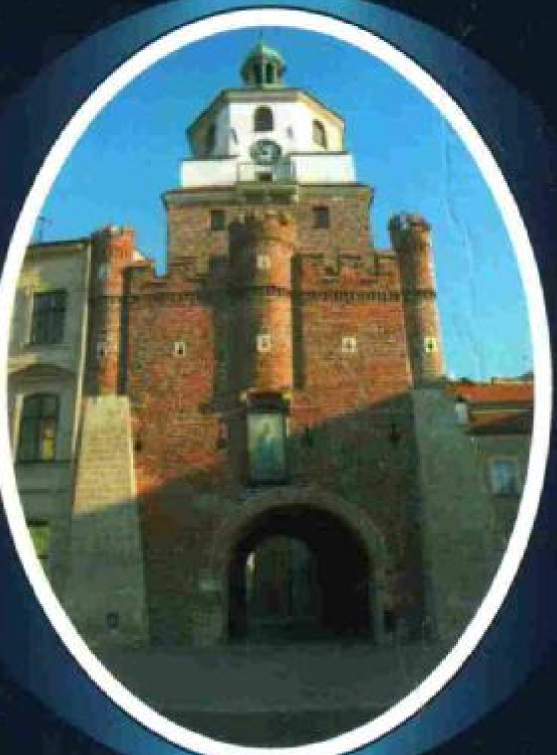
ISSN 1730-8658

MOTROL

MOTORYZACJA I ENERGETYKA ROLNICTWA

MOTORIZATION AND POWER INDUSTRY IN AGRICULTURE



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LUBLIN 2010

COMMISSION OF MOTORIZATION AND POWER INDUSTRY IN AGRICULTURE
POLISH ACADEMY OF SCIENCES BRANCH IN LUBLIN
NATIONAL ACADEMY OF NATURE PROTECTION
AND RESORT DEVELOPMENT
THE VOLODYMIR DAHL EAST-UKRAINIAN NATIONAL UNIVERSITY
UNIVERSITY OF LIFE SCIENCES IN LUBLIN

MOTROL

MOTORIZATION AND POWER INDUSTRY IN AGRICULTURE

Volume 12 D

SYMFEROPOL - LUBLIN
2010

ISSN 1730—8658

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MOTROL, 2010, 12D, 48-57

ENERGY-EFFICIENT BOREHOLE PUMPS BASED ON AXIAL STAGES OF LOW SPECIFIC SPEED

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Summary. Perspectives of application of axial flow parts of low specific speed in submersible borehole pumps, used for artesian water supply, are considered in this article.

Key words. Water supply, artesian borehole, axial flow part, efficiency of pumping equipment, ECW type pumps.

INTRODUCTION

The problem of qualitative drinking water supply for population became aggravated recently in Ukraine, which is underprovided region of Europe on reserve of water resources. [Shepelenko A., 2009]. At the present time two basic sources of the centralised water supply exist in Ukraine - a surface water and artesian boreholes. The second type of water supply has a number of advantages - the maximum proximity to the consumer, cleanliness of extracted water which is less subjected to anthropo- and technogenic influence, profitability of operation of water supply points on their basis. It is worth to notice that power consumption for water lift makes a considerable share of boreholes power input and, consequently, electric power payment makes a considerable share of the lifted water cost. Considering that borehole pumps mainly operate round-the-clock on artesian water supply points, even at rather small increase of efficiency of their operation it is possible to get considerable economic benefit. In connection with this, efficiency of the pumping equipment becomes one of the major factors when choosing it.

PROBLEM STATEMENT

Generally, electric power surcharge during borehole pumps operation is connected with use of the out-of-date and power-intensive equipment on water supply points.

Ukrainian water canals widely use pump units of ECW type (E – electric drive, C - centrifugal, W - for water) for artesian water extraction which basic cofigurations (I, II, III and IV), which are presented in fig. 1.

Operation of the given type pumps is attended by a number of problems [Zhuplov, 2005] - low value of average service efficiency, short term of operation before repair (9-12 months), increased pump parts wear that in turn leads to the considerable electric power surcharge and low repairability of the pump.

Besides in many cases pump parametres and its efficiency are essentially underestimated in relation to the data given in catalogues [Sandik A, 2010] and do not meet modern requirements to these pumps.

In most cases, the reason may be that domestic producers of pumps choose the technical decisions directed on minimisation of the product price when designing [Bolgov A, 2007], use inexpensive short-lived materials and simplified manufacturing techniques when manufacturing, that frequently negatively affects quality of the product and its life term.

Such situation is possible until pump equipment consumers, considering offers-analogues, will prefer variants with the least initial cost, without paying attention to operation cost.

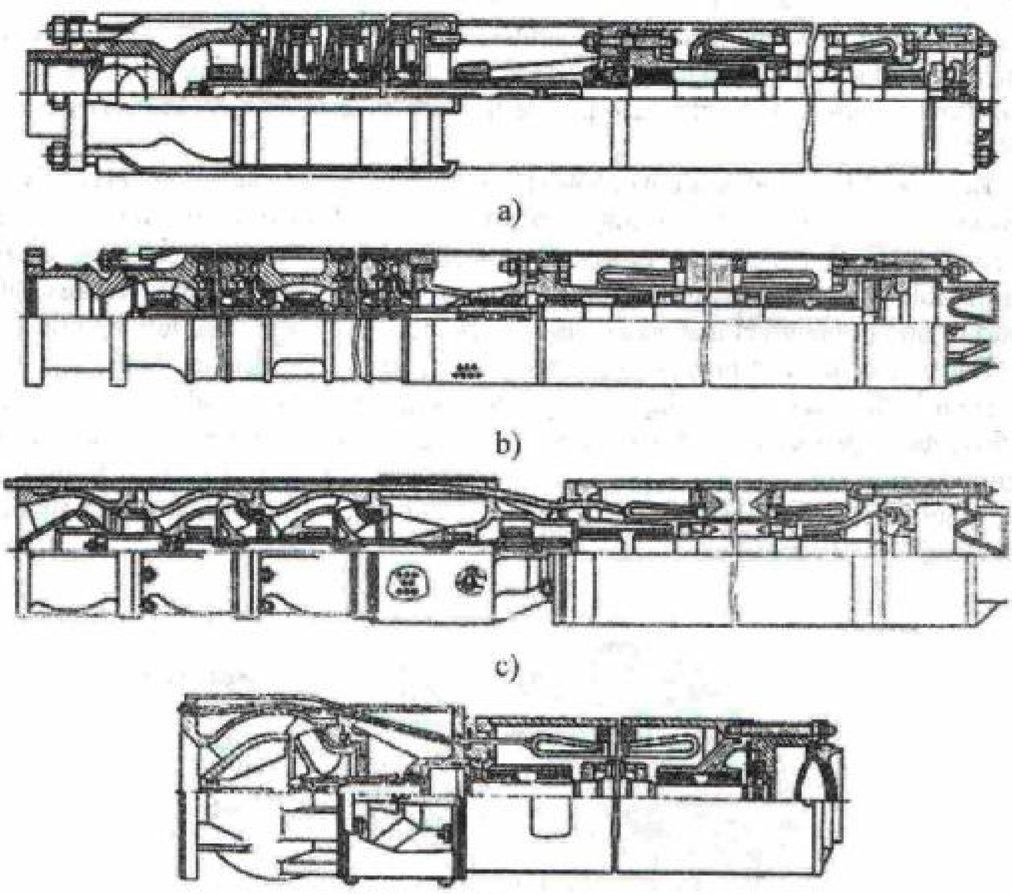

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Fig. 1. Basic construction arrangements of ECW type pumps: a) Configuration 1. Pumps with impellers, fixed on a shaft, the axial force is compensated by the support device located in the electric motor, vaned tap collars are stamped; b) Configuration 2. Pumps with cylindrical collars, made of pipes with disks which fix taps in axial direction, divide interstage cavities and form groove seals of impeller; c) Configuration 3. Pumps with cast ("pot") vaned taps, pump stages are of diagonal type, impellers are fixed on a shaft, the axial force is compensated by the support device located in the electric motor; d) Configuration 4. Monoblock electropump units (the impeller is located on an electric motor shaft)

BASIC PART

World practice of operation cost estimation of the puming equipment is based on consideration of the costs sum throughout life cycle of a product or LCC (Life Cycle Cost) [Tverdohleb I., 2008] which shows that initial cost is only small share of cost of "life cycle" of pumps.

The analysis of life cycle cost is intended for minimisation of the general expenses, maximisation of power efficiency of pump systems and finding the most economic decisions. Components of the analysis of life cycle cost usually are initial cost, cost of installation, electric power costs, operating costs, repair costs, downtime costs, ecological costs, recycling costs - that is the sum of all items of expenses.

According to researches [Lars. F, 2001], the purchaser pays only 5 % from a total sum which he should pay throughout all operation life when purchasing borehole pump for lifting of drinking water, thus costs for payment of the consumed electric power will make about 84 %.

Results of LCC calculations show domestic pumps to have lower level of LCC in comparison with foreign ones nowadays. But this fact is mostly connected with electric power lower price. When electric power price increases and becomes closer to European level, preferable choice for domestic pump equipment will be not so clear. Because of this, major part of pump manufactures considers their pumping equipment should be improved.

Basic directions of improvement are going from LCC analysis. Some of them are clear enough: efficiency increasing, service life term increasing, reliability and repair-ability features improvement. Domestic and foreign pumps comparative analysis made some pump manufactures to carry out ECW pumps improvement programs. Major aim of those programs was to increase reliability features and efficiency value of borehole pumps, and therefore LCC decrease.

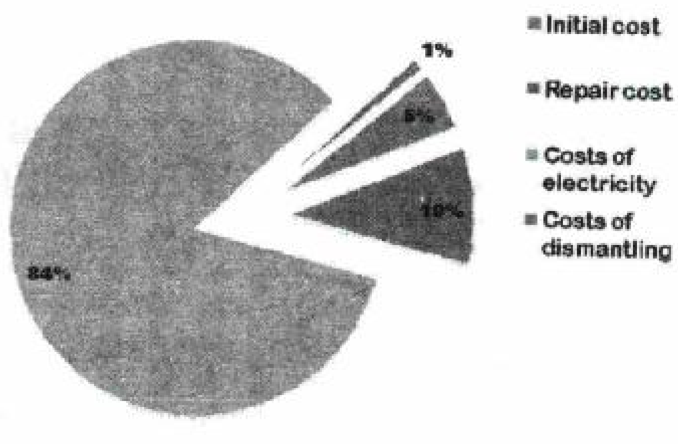

Fig. 2. Life Cycle Cost of the borehole pump for water

Nowadays to solve problems of ECW pump operation manufactures mostly use two directions – driven motor improvement and pump part improvement.

Driven motor improvement is mostly devoted to designing and producing leak-proof (hermetic) immersion driven motor. It is to exclude contact of internal motor chamber with handled medium, which can contain abrasive and aggressive impurities. In such a way motor life duration will be increased significantly, and motor will be running steadily during all operation life.

In most cases pump part improvement includes two directions. Firstly – improvement of seals between impellers and at impellers suction side, pump bearings improvement with new designs development and wear resistance material using. Secondly, it's properly flow part features improvement.

It's important to mention that borehole pumps of ECW type standard size series was based on the standard which had been developed in former USSR (GOST 10428-89). That standard was mostly devoted to operation of low yield boreholes. At the same time analysis of world company-leader borehole pumping units parameters changing during last time has showed steadily tendency to pump flow increasing on the one hand and pump diametric dimension decreasing on the other hand. Such tendency is connected with high increase of boreholes building and equipping cost under borehole diameter increase. Besides, using pumps with enlarged flow allows decreasing operational costs, pipeline building costs, amortization costs and others for 10-20% relative recovered water volume.

Mixed flow pump stages, which are used for increasing flow under limited overall dimensions, have several disadvantages: producing technologies are becoming more complicated, axial overall dimensions and material intensity are increasing, therefore pump cost is increasing too. In addition, ensuring mixed flow pump stages operation under flows, which are larger than values mentioned in GOST 10428-89, is complicated task because of several reasons.

Well-known designs [Papir A., 1955] analysis has shown ability for changing mixed flow pump stages to axial flow pump stages of low specific speed (ns<400). It is worth to notice that axial flow pump have the highest efficiency values among all blade pumps. When using flow part with ns<400 we can expect efficiency value to stay at high enough level. Such a flow part has several advantages:

- high hydraulic efficiency level (around 87-92%);
- it provides the simplest and the most compact design for given parameters, what is highly important for boreholes limited dimensions;
- axial hydraulic parts with opened channels have simpler technology in casting manufacturing than opened centrifugal ones, they allow wide spread wear resistance materials with low cast features using; it allows insuring stable pump parameters under operation and increase pump service life sufficiently;
- under axial flow impellers wear during operation, axial force (which is one of the most destructive factors for ECW type pumps) does not increase, as in centrifugal units, but decreases that on the one hand allows to increase considerably resource of reference node and the pump in whole, and on the other hand - to avoid the raised power consumption.

But it seems that determinant for axial executives usage in borehole pumps for water supply is that they give the chance to raise pump feed dramatically (in 1,5 - 2 times) in comparison with centrifugal stages. When there are boreholes with high yield on a water supply point it is possible to increase volume of extracted water in 1,5 - 2 times with the minimum capital expenses - without new boreholes building. Hence, usage of axial stages for improvement of borehole pumps gives a number of advantages both concerning pump design, and borehole - pump - piped network - consumer system.

Axial flow parts with the lowered specific speed (ns <400) may be considered as a basis for creation of standard size series of submersible borehole multistage pumps intended for replacement of existing ECW type pumps designs.

The basic consumers of such pump units traditionally are municipal engineering, industrial and other enterprises, which need lifting of great volumes of water from boreholes for purpose of water supply, dewatering or water drain.

For creation of such series it is necessary to outline parametres of base flow parts, which will be the base for the standard size series. It is worth to notice that existing design procedures of axial pumps are well developed for the flow parts which specific speed equals 700…1000, therefore we cannot say that they will show adequate results when using for axial stages of low specific speed. Therefore as the first step it is reasonable to inspect existing design procedures. As a result of check it will be possible to choose a technique which provides the results closest to design and to adapt it to necessary conditions, or to create the new one.

For the analysis of possibility of application of existing methods of flow parts designing of axial pumps when producing axial pumps of low specific speed we selected three ones of the most often applicated in practice. It is Voznesensky-Pekina method [Lomakin A, 1966], method of lifting forces [Mihajlov A, 1977] and method, which major statements were stated in D.JA.Sukhanov, V.I.Bogdanovskogo, A.S.Ereminoj's studies and their pupils [Large axial and centrifugal pumps, 1977].

The analysis was carried out by comparisons of the design data with results of numerical simulation. For this purpose designing of impellers for the parametres, specified in table 1, was carried out, and then numerical experiment was made.

Table 1. The initial data for designing

Flow coefficient, K_Q	Head coefficient, K_H	Specific speed coefficient, ns	Rotation speed, rev/min	Borehole overall dimension, inches
0,185	0,249	267	2900	10

When designing of the axial impeller using the third method the geometry of very difficult spatial form, with a sharp gradient of corners of the blade installation and meredional projections length along radius was obtained. Such flow part would be very difficult in manufacturing, besides, for the blade of the received form the durability condition is not satisfied. Possibly, the reason of such results is that in a basis of the given method empirical factors of circulation distribution and flow component of absolute velocity along the radius, introduce for specicifc speed values for a range 700...1000 that dramatically differs from stage specific speed , given in table 1. Therefore it was decided not to carry out numerical simulation for the given impeller.

The technique and order of carrying out of numerical experiment did not differ from described in work [Kaplun I, 2009].

The computational grid (fig. 3) has been created in a component of program complex ANSYS of the university version, and contained 647 thousand cells. For the appropriate description of boundary layers close to solid walls density of a grid was increased.

The magnitude of variable Y + was in range from 10 to 100 units that meet the requirements given in the user manual of the specified software product.

Calculation of fluid flow in channels of examined impellers has been carried out by means of software product ANSYS CFX which academic version is at the disposal of SSU. Simulation was carried out for water in range of feeds from 0,7 Qрачс to 1,2 Qрасч.

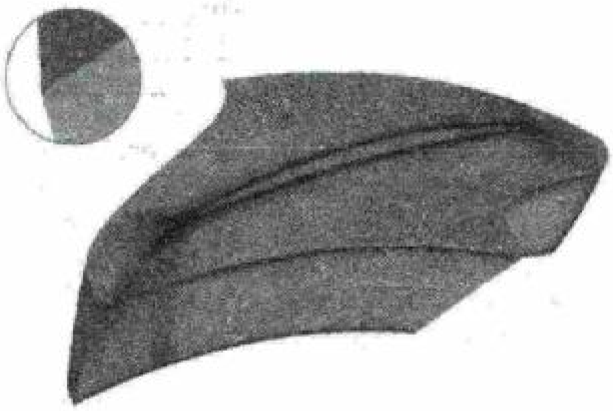

Fig. 3. An example of the computational grid in the impeller channel

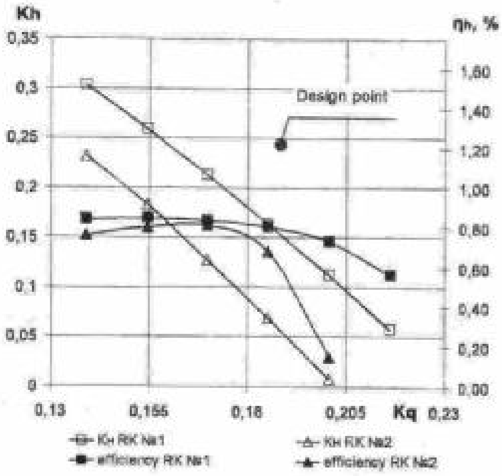

Fig. 4. Head and energy characteristics of axial impellers RK №1 and RK №2

The impellers characteristics, received as a result of numerical simulation are presented in fig.4. Hereinafter the impeller RK №1 was designed by a method Voznesensky-Pekina, RK №2 – by a method of lift forces. As it was supposed, there are considerable divergences between the parametres of impellers accepted at calculation and those, which were received as a result of numerical experiment for calculated feed. The quantitative estimation of divergences is presented in table 2.

Both for the first, and for the second impeller optimum value of feed is less than calculated one. Besides, the curve of RK №2 head characteristic has more abrupt slope.

In an optimum point head coefficient is equal approximately KH=0,26 at η =84 % for RK №1, and KH=0,18 at η =81 % for RK №2.

Table 2. Quantitative divergences of values accepted at designing and those, which were received as a result of numerical experiment

	PK № 1	PK № 2
K_{Qdes}- K_{Qopt}, %	-16,8	-8,1
K_{Hexp} -K_{Hdes}, %	-34,5	-71,9
K_{Hdes}- K_{Hopt}, %	+4,4	-27,7

Distribution of flow component of absolute velocity at input and output from the impeller along scope of the blade for optimum mode is presented in fig. 5. Considerable difference in velocity profile at output from RK №1 and №2 for almost identical velocity profiles at input in the impeller attracts our attention. Profile has considerable non-uniformity in near-bushing areas for RK №2. Velocity profile non-uniformity can be quantitatively estimated by means of the following coefficient:

$$K_{Vm} = \frac{V_{mi}}{\overline{V_m}} , \qquad (1)$$

where: V_{mi} - value of flow component of velocity at current radius, m/s;

$\overline{V_m}$ - mass feed-averaged value of flow component of absolute velocity, m/s.

Similarly:

$$K_{Vu} = \frac{V_{ui}}{\overline{V_u}} , \qquad (2)$$

where: V_{ui} - value of circumferential component of velocity at current radius, m/s;

$\overline{V_u}$ - mass feed-averaged value of circumferential component of absolute velocity, m/s.

This coefficient equals 1,17 in near-bushing area for RK №2 in comparison with its value for RK №1, which equals 1,04.

For both impellers considerable by the size (about 30 % of the blade height) area since with lowered flow component of absolute velocity occurs on a peripheral part of blades. The reason of this area occurrence is tip eddy, which results from interaction with the basic fluid flow through a radial clearance between end face of the impeller blade and its chamber.

Distribution of periferal component of velocity at output from impellers for optimum mode is presented in fig. 6. The profile data shows the reserved tendency - the profile for RK №2is almost linear approximately to half of the blade height, and deformation with increase of peripheral component of velocity occurs only on peripheral part, and the profile for RK №1 has more non-uniform character. It is obvious that the cross-sections close to the middle of the blade height provide the lowered head in RK №1.

Distribution of head coefficient along scope of the blade for optimum mode is illustrated in fig. 7. This distribution for RK №1is close to linear law, which means that all cross-sections of the impeller blade provide fluid transfer of almost identical energy. Unlike RK №1, peripheral sections of the blade in RK №2 develop 12,7% higher head compared to averages or near-bushing values.

As a whole numerical simulation has confirmed the initial assumption of necessity of existing design procedures correction when designing of axial impellers of low specific speed. According to the results of numerical simulation it is reasonable to give preference to Voznesensky-Pekin method, as such that provides values of head close to calculated values and higher value of efficiency. At the same time it is not excluded that the reason of more considerable divergences in the results received for PK №2 is disagreement between range of values defined by empirical relations, to the impeller working conditions.

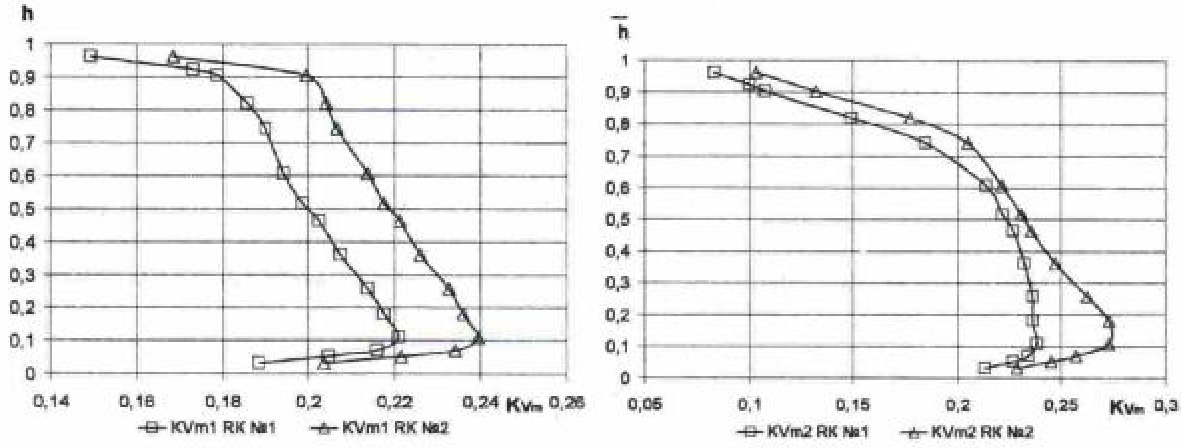

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Fig. 5. Profiles of flow component of absolute velocity for optimum mode: a) at input in RK №1 and RK №2, b) at output from RK №1 and RK №2

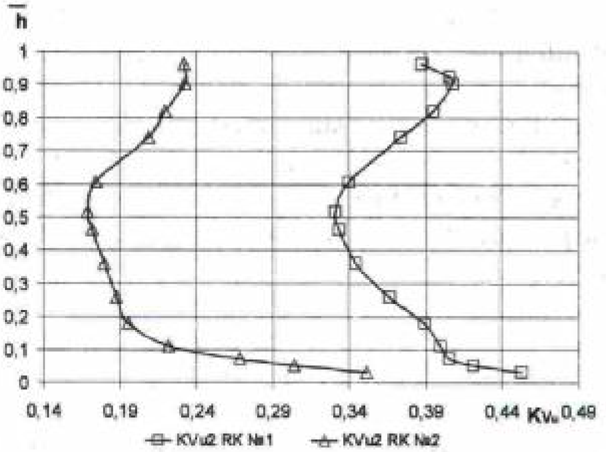

Fig. 6. The profiles of peripheral component of velocity for optimum mode at output from RK №1 and RK №2

Therefore for making well-founded solution, concerning a choice of a basic technique for the further adaptation of the specified range of axial impellers specific speed, work in the specified direction should be continued by obtaining new experimental coefficients.

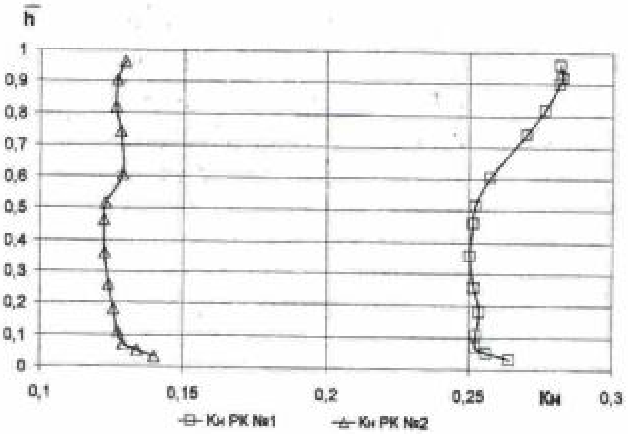

Fig. 7. Distribution of head coefficient along the blade height for optimum mode for RK №1 and RK №2

CONCLUSIONS

1. The basic construction arrangements of submersible borehole pumps of ECW type were considered in the article. The basic problems of this type pumps operation, and besides the reasons of their occurrence were analysed.

2. The order of definition of life cycle cost of the pump was considered, and it was specified that about 84 % of life cycle cost of the pump make costs on electric power payment.

3. Perspectivity of change of diagonal flow parts for axial low specific speed flow parts, because the last type has hydraulic efficiency of high value and can provide high values of feed for minimum radial dimensions that is especially important for operating conditions of boreholes.

4. As a result of numerical simulation of fluid flow in the impellers designed by different methods, head and power characteristics, velocity profiles, and distribution of head coefficient along radius have been obtained. It was defined that the considered design procedure does not provide sufficiently exact results when calculating axial flow parts of low specific speed.

REFERENCES

1. Bolgov A.A, 2007: Modernizacia nasosov tipa ECW.Novie konstrukcii i tehnologicheskie reshenia. - Reforma GKH №3, Moskow. - p.34-35. (in Russian).
2. Zhuplov B., 2005: O ekspluatacii pogruzhnih skvazhinnih nasosov. - Nasosi i oborudovanie №2(31)-3(32), Kyiv. - p.38-39. (in Russian).

3. Kaplun I., Demchenko O., 2009: Chiselne modeluvannai techii gazoridinnoi symishi v malogabaritnij shnekoij stupeni sverdlovinnogo nasosy. - Visnik Sumskogo derzhavnogo universitety. Seria tehnichi nayki №4, Sumy. - p.36-44. (in Ukrainian).
4. Lars F., ... [et al], 2001: Pump Life cycle costs. A guide to LCC analisys for pumping systems. - Hydraulic institute Europump. New Jersey. 2001. 194 p.
5. Lomakin A., 1966: Centrobezhnie i osevie nasosi. - Moskow: "Mashinostoenie". 364 p. (in Russian).
6. Mihajlov A., Malushenko V., 1977: Lopastnie nasosi. Teorija, rascheti i proektirovanie. - Moskow: "Mashinostoenie". 288 p. (in Russian).
7. Papir A., 1955: Malogabaritnie glubinnie nasosi. - Trudi Leningradskogo politehnicheskogo instituta im. Kalinina. №177, Sankt-Peterburg. - p. 42-48. (in Russian).
8. Shepelenko A., Yevtushenko A., Kaplun I., 2009: Vdoskonalennia protichnih chastin nasisiv tipy ECW. - Promislova gidravlika i pnevmatika №3 (25). - p.49-54 (in Ukrainian)
9. Tverdohleb I., Kostuk A., Knjazeva E. Solodchenkov V., 2008: Snizhenie stoimosti zhiznennogo cikla pogruzhnih nasosov tipa ECW dlia vodi. - Trudi 12 mezhdunarodnoj naucho-tehnicheskoi konferencii "GERVIKON-2008". Sumy. - p. 379 - 386. (in Russian).
10. Sandik A, 2010: O nasosostroenii v Ukraine. - Nasosi i oborudovanie №2(61), Kyiv. - p.38-39. (in Russian).
11. Krupnie oseie i centrobezhnie nasosi. Montazh, ekspluatacia i remont. Spravochnoe posobie, 1977. - Moskow: "Mashinostoenie".(in Russian).

ЭНЕРГОСБЕРЕГАЮЩИЕ СКВАЖИННЫЕ НАСОСЫ НА ОСНОВЕ ОСЕВЫХ СТУПЕНЕЙ НИЗКОЙ БЫСТРОХОДНОСТИ

Аннотация. В статье анализируются перспективы применения осевых проточных частей низкой быстроходности в погружных скважинных насосах, используемых для артезианского водоснабжения.

Ключевые слова: водоснабжение, артезианская скважина, осевая проточная часть, эффективность насосного оборудования, насосы типа ЭЦВ.

СОДЕРЖАНИЕ