

Determination of The Rational Width of The Second Stage of Two-Stage Liquid Ring Vacuum Pumps of Modified Design

^{1,2}Rodionov Yuri Viktorovich, ³Al-Maidi Ali Abbas Hashim, ⁴Ali Al-Jubainawi, ²Nikitin Dmitry Vyacheslavovich, ¹Sukhova Anna Olegovna, ¹Glivenkova Olga Anatolyevna, ¹Chumikov Yuri Anatolyevich, ¹Rybin Grigory Vyacheslavovich

¹FGBOU VO "Tambov State Technical University"

²Federal State Budgetary Educational Institution of Higher Education Michurinsk State Agrarian University

³University of Misan, College of Agriculture, Iraq.

⁴University of Misan, College of Engineering, Iraq

Corresponding authors: rodionow.u.w@rambler.ru¹; ali_abbas@uomisan.edu.iq³; alihussein.mcm@uomisan.edu.iq⁴;

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Abstract:

The purpose of the study is to obtain a two-stage modified liquid ring vacuum pump to reduce energy consumption, consumption of additionally supplied working fluid, as well as increase efficiency when using working fluids of various viscosities. The technological characteristics of a vacuum pump are directly affected by its design parameters, the optimal calculation method of which can provide a number of advantages. The presented modified designs of liquid ring vacuum pumps can significantly reduce the costs of organizing vacuum in technological processes of agricultural production. The presented method for determining the width of the second stage casing makes it possible to achieve a reduction in energy consumption during operation and an increase in the speed of action (performance) of the vacuum pump.

Keywords: Vacuum pump, energy consumption, efficiency, agricultural production, operating speed

Introduction:

At present, the agricultural sector is one of the most dynamically developing. It is filled with fundamentally new, as well as modernized technologies and equipment. At the same time, the most important task in improving is to increase efficiency, as well as reduce energy consumption and the cost of both equipment and the manufactured product [1].

Vacuum technologies have found wide application in the agricultural sector [2]. They are used in the processes of production and processing of crop and livestock products. In particular, for pneumatic transport, drying, extraction and evaporation. At the same time, the air pumped out during the described processes contains a large number of impurities, for example, during pneumatic transport this is dust and particles of the transported material, and during heat and mass exchange processes - liquid vapor. This necessitates the use of a filtration system for the sucked air or the use of special designs of vacuum pumps.

The most suitable for this is a liquid ring vacuum pump [3]. Its design consists of a housing in which an eccentrically mounted impeller with blades spins the liquid poured into the pump, thereby forming a liquid ring. Thus, air is pumped out due to a gradual increase and then decrease in the volume of the working cell, which is limited at the ends by the covers of the vacuum pump, at the top by an impeller with blades and at the bottom by a liquid ring. The use of this type of pump allows minimizing or completely eliminating from the system the equipment for filtering the air entering the pump. Therefore, research into pumps of this type attracts the attention of scientists from all over the world [4-8].

Liquid ring vacuum pumps are single- and two-stage. The latter are used to obtain a deeper vacuum, for example, when it is necessary to carry out heat and mass transfer processes at low temperatures (about 30 ° C).

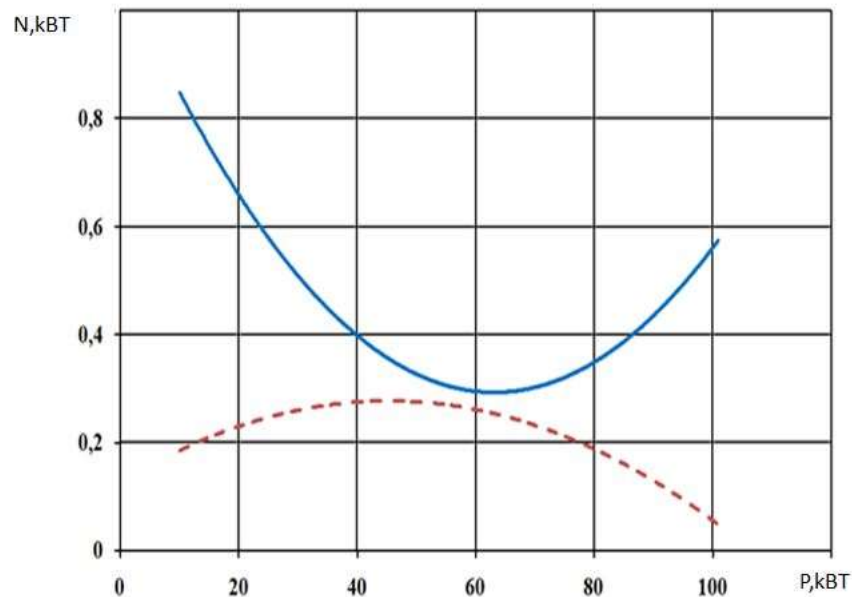
However, classic designs of liquid ring vacuum pumps are characterized by high power costs and low efficiency. Currently, these problems are being solved by improving the designs of vacuum pumps of this type.

Methodology.

At the Tambov State Technical University (Russia), active development of new designs of liquid ring vacuum pumps is underway at the Scientific and Educational Center "Ecotechnologies named after Yu.G. Skripnikov". In particular, single-stage vacuum pumps with a mechanism for automatic regulation of the discharge window flow area, as well as a rotating body, have been developed. Two-stage vacuum pumps have also been developed with the implementation of the improvements described above, as well as separated shafts of the first and second stages, which are connected by a clutch or variator, and a system of distributed end supply of the working fluid [9,10].

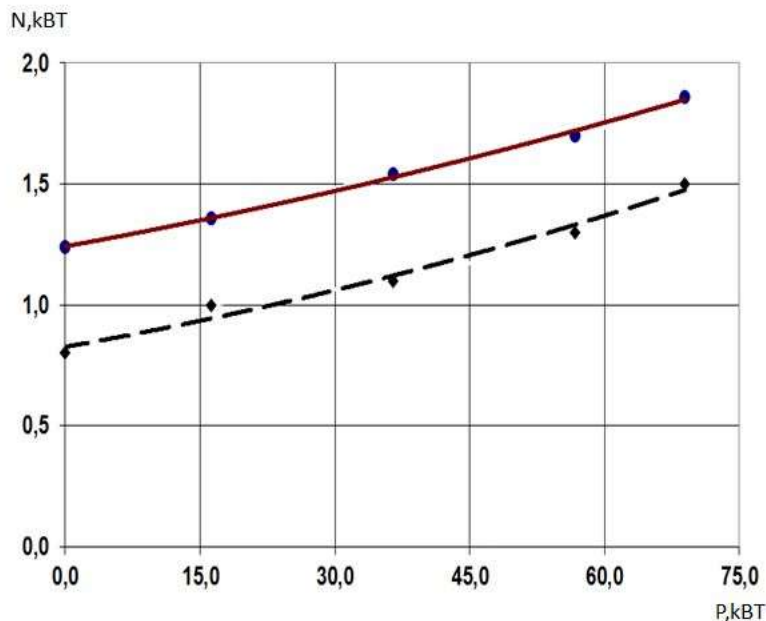
The presented modifications make it possible to significantly reduce power costs during the operation of vacuum pumps and increase their efficiency, which has been proven experimentally [11-12].

Savings in effective power when using a mechanism for regulating the discharge window depending on the operating mode (vacuum pressure) have been obtained experimentally (Fig. 1) [11].



Rice. 1 – Graph of the dependence of the effective power on the vacuum depth of a high-pressure liquid pump with an automatically adjustable discharge window[^]
 – ZhVN; --- ZhVN RNO

Similarly, an experimental dependence of effective power savings was obtained depending on the operating mode (vacuum pressure) when using a rotating casing engaged with the impeller blades (Fig. 2) [12].



Rice. 2 – Graph of the dependence of the effective power on the vacuum depth of the liquid pump with the kinematic connection of the impeller and the rotating casing:

● – ZhVN NK; ◆ – ZhVN KZ

Results and discussion:

The obtained effects are explained by the fact that when operating only at the first stage with rotation of the liquid pump housing due to the kinematic connection of the housing blades and the impeller blades, the coefficient of hydraulic friction is determined by the Altschul formula of the following form:

$$\lambda_T = 0,11 \left(\frac{68}{Re} \right)^{0,25}$$

Where λ_T – coefficient of hydraulic friction, Re – Reynolds criterion

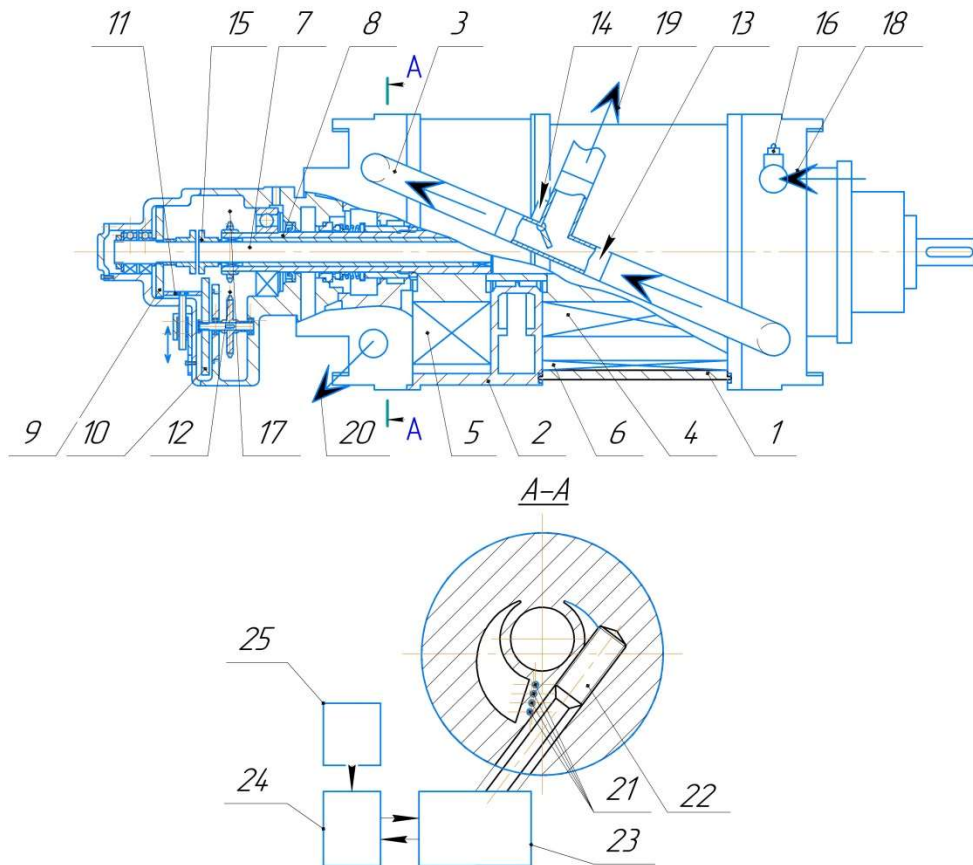
The work used analytical methods for obtaining theoretical regularities based on known laws and expressions. Energy efficiency was determined analytically by comparing expressions for determining the required power for vacuum pumps of basic and modified designs. Some of the expressions presented in the article were obtained using the licensed version of the Maple software package.

Results of improvement :

When the second stage of a two-stage liquid ring pump of a modified design is operating, the compression power $N_{\text{сж}}$ of the vapor-gas mixture in it is a function of the angular speed of rotation of the impeller min^{-1} , the average speed of fluid movement in the bladeless and bladed spaces $v_{\text{ср}\phi}$ m/s and the internal compression ratio τ :

$$N_{\text{сж}} = f(\omega, v_{\text{ср}\phi}, \tau)$$

As noted earlier, the modified two-stage liquid ring vacuum pump is aimed at reducing energy consumption, the consumption of additionally supplied working fluid, and increasing the efficiency when using working fluids of different viscosities. A two-stage liquid ring vacuum pump of a modified design of the first type (Fig. 3) [13] consists of a housing of connected housings of the first 1 and second 2 stages, through which shaft 7 passes and which. In this case, the outlet pipe of the first stage is connected to the inlet pipe of the second stage by pipe 3. In the casing of the first stage, an impeller is installed on the shaft, which during operation is engaged by the blades of the casing 6.



1 – first stage casing, 2 – second stage casing, 3 – connecting pipe, 4 – first stage impeller, 5 – second stage impeller, 6 – casing blades, 7 – first stage shaft, 8 – second stage hollow shaft, 9 – left front variator disc, 10 – right front variator disc, 11 – intermediate roller, 12 – chain drive, 13 – tee, 14 – electromagnetic damper, 15 – electromagnetic clutch, 16 – pneumoelectric sensor, 17 – housing, 18 – gas inlet phase, 19 - movement of the gas phase when operating at one stage, 20 - movement of the gas phase when operating at two stages, 21 -

mechanism for regulating the size of the flow area of the discharge window, 22 - mechanism for regulating the size of the flow area of the discharge window, 23 - drive of the size control mechanism flow area of the discharge window; 24 – control unit, 25 – tracking system

Rice. 3 – Two-stage liquid ring pump with kinematic closure of the first stage and an adjustable discharge window of the second:

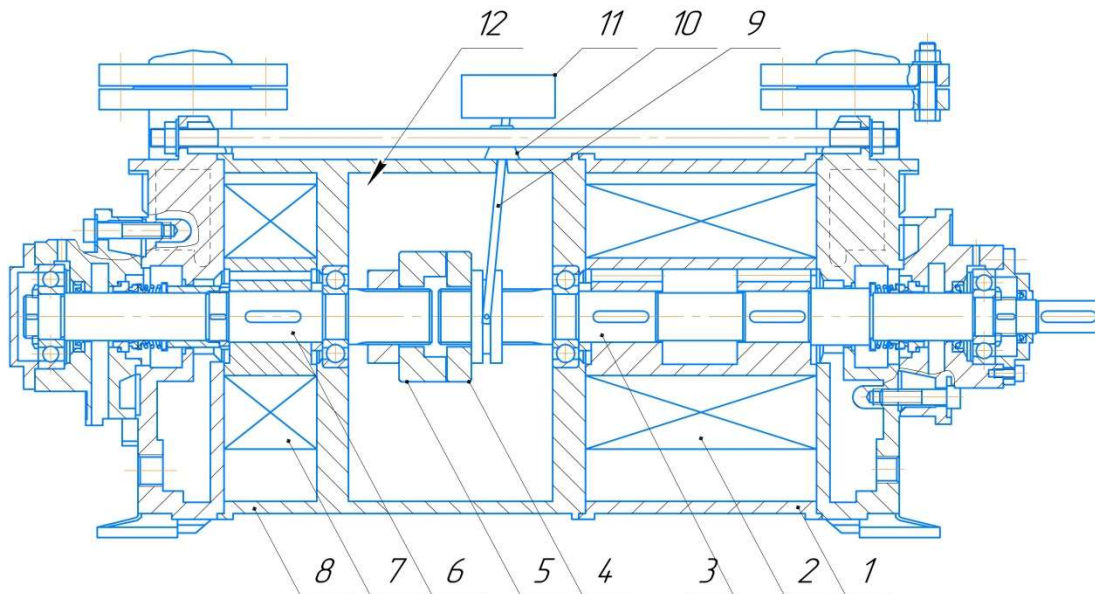
In the housing of the second stage 2, a hollow shaft 8 is installed on the shaft 7, which are connected to each other through a frontal variator. The impeller of the second stage 5 is installed on the shaft 8. Also, the second stage is equipped with a mechanism for regulating the flow area of the discharge window 22, which is regulated by an automation system consisting of blocks 23-25. Each of the chambers has end openings 21 on both sides for supplying additional working fluid, which allows minimizing power losses due to end leaks. In the case of operation of only the first stage of the pump, air with liquid leaves the pump in direction 19, for which pipe 3 is equipped with a tee 13 with an electromagnetic damper 14. In the case of operation of two stages, the electromagnetic damper closes and the air with liquid from the first stage is directed to the second and exits from it in direction 20.

Also for this design, the optimal scheme for supplying the working fluid has been determined, expressed in the distribution of the entire supplied volume as a percentage between stages depending on the operating mode (Table1)

Table 1 – Scheme of distribution of working fluid supply between stages depending on the operating mode.

Mode	Vacuum pressure, kPa	Distribution of the additional volume of working fluid between the first and second stages, respectively, %: %
Blower	101	1:0
Vacuuming	from 101 to 31	0,75:0,00
Vacuuming	from 31 to 2	0,75:0,25
Vacuum support	2	0,5:0,5

When using water as a working fluid, the most effective is the use of a two-stage liquid ring vacuum pump of a modified design of the second type (Fig. 4). It differs from the first type of modification by the absence of a variator.



1 – first stage housing, 2 – first stage impeller, 3 – first stage shaft, 4 – driving cam coupling half, 5 – driven cam coupling half, 6 – second stage shaft, 7 – second stage impeller, 8 – second stage housing, 9 – second stage connection lever, 10 – cuff, 11 – automatic control unit, 12 – intermediate chamber.

Rice. 4 – Two-stage liquid ring vacuum pump with two shafts:

Each stage has its own independent shaft, with a splined groove at the end. The driven coupling half 5 is fixed motionless relative to the shaft, and the driving coupling half 4 can move along the shaft using a lever controlled by an automatic control unit (ACU). At the initial stages of operation, the driving half of the coupling is moved away from the driven half and only the first stage operates. After the ACU receives a signal from the pneumoelectric sensor installed at the input of the first stage, the control unit moves the lever to the opposite position and connects the second stage. This technological solution can significantly reduce the power consumption and cost of the pump in comparison with a two-stage liquid ring pump of a modified type 1 design.

The width of the second stage depends on the maximum pressure created by the two-stage liquid ring vacuum pump, which in turn depends on the set pressure ratio of the entire pump and, as a consequence, the pressure ratio of the first stage. Then the width of the second stage b_2 is determined as the ratio of the width of the first stage b_1 to the degree of pressure increase in it τ_1 . At the same time, we make the assumption that there are no losses in interstage communications, i.e.

$$b_2 = \frac{b_1}{\tau_1}$$

where b_2 is the width of the second step, m; b_1 – width of the first step, m; τ_1 – degree of pressure increase in the first stage.

The algorithm for preliminary determination of the width of the second step is as follows.

We determine the degree of pressure increase of the vacuum pump under study:

$$\tau_{\text{ycr}} = \tau_1 \cdot \tau_2$$

where τ_{yst} is the degree of pressure increase of the vacuum pump, τ_2 is the degree of pressure increase of the second stage.

Also, the degree of pressure increase in a two-stage liquid ring vacuum pump in vacuum support mode can be determined as:

$$\tau_{\text{ycr}} = \frac{P_{H2}}{p_1}$$

where P_{H2} is the discharge pressure of the second stage, Pa; p_1 – suction pressure in the first stage, kPa.

Knowing the degree of pressure increase in the vacuum pump, we can determine the degree of pressure increase in the first stage as:

$$\begin{cases} \tau_1 = 0,2\tau_{\text{ycr}}, & \tau_{\text{ycr}} = 10...15 \\ \tau_1 = 0,075\tau_{\text{ycr}}, & \tau_{\text{ycr}} = 10...50 \end{cases}$$

The accepted assumption, as well as the error in the experimental methodology, do not allow us to consider the obtained dependence sufficiently acceptable when designing modified designs of liquid ring vacuum pumps.

To test the proposed algorithm for determining the width of the second stage, an analytical determination of the effective power of the vacuum pumps under study when operating at both stages is proposed, and the switching pressure of the second stage p^* is taken into account in the calculation as:

$$p^* = \frac{101,3}{\tau_1^m \cdot 0,8}$$

where p^* is the switching pressure of the second stage, kPa; m – polytropic index.

Moreover, when turning on the second stage of a liquid ring vacuum pump, the test condition is when the pressure in the inlet pipe is less than in the last discharge cell or vice versa:

$$p_{\text{cж}} \geq p_{\text{H}} = p_{\text{atm}}$$

where $p_{\text{cж}}$ – compression pressure, kPa; P_{H} – discharge pressure, kPa; P_{atm} – atmospheric pressure, kPa.

Moreover, when using a mechanism for regulating the flow area of the discharge window, it makes it possible not to have reverse currents of the vapor-gas mixture, and to calculate the discharge pressure in the first stage, use the formula:

$$p_{\text{H1}} = p_{\text{cж1}} = p\tau_1^n - \Delta p_{\text{yT}}$$

where p_{H1} – discharge pressure in the first stage, kPa; $p_{\text{cж1}}$ – compression pressure in the first stage, kPa; p – suction pressure, kPa; Δp_{yT} – pressure loss due to gas phase leaks, kPa.

Based on experimental studies, pressure loss is determined as:

$$\Delta p_{yT} = 0,2\tau^n p_1$$

To eliminate the shortcomings, the design includes an intermediate chamber between the housings of the first and second stages, as well as a variator, which allows the shaft of the second stage impeller to rotate at a speed different from the speed of the first stage shaft, as well as change the speed of the second stage shaft in the process.

Based on this, we have the following equalities:

$$\begin{aligned} V_k + V_{\Pi} &= V_2; \\ p_{H1}V_{H1} &= p_2V_2 = p_2(V_k + V_{\Pi}), \end{aligned}$$

Where V_k – volume of connecting communications between the first and second stages, m^3 ; V_{Π} – volume of the intermediate chamber, m^3 ; V_2 – volume of the second stage suction chamber, m^3 .

Moreover, when designing:

$$\begin{cases} a = \frac{\tau_1}{\tau_2} = \frac{\tau'_2}{\tau_2}, \\ a \geq 1; \end{cases}$$

Where τ_2 – degree of pressure increase of the second stage without taking into account expansion in the intermediate chamber

$$b_2 = \frac{b_1}{\tau_1} a$$

The effective power of a two-stage modular liquid ring vacuum pump is determined by the formula:

$$N_e = N_{c\kappa 1} + N_{c\kappa 2} + N_{\delta_{\Pi 1}} + N_{\delta_{\Pi 2}} + N_{k1} + N_{k2} + N_{Tp} + N_{\text{э}1}$$

Where $N_{c\kappa 1}, N_{c\kappa 2}$ – powers spent on compression of the vapor-gas mixture in the first and second stages; $N_{\delta_{\Pi 1}}, N_{\delta_{\Pi 2}}$ – powers expended to overcome fluid friction forces in the bladeless space of the first and second stages; N_{k1}, N_{k2} , - powers expended on rotation of the liquid in the impellers of the first and second stages; N_{Tr} – power expended on mechanical friction; $N_{\text{э}1}$ is the power expended on the involute engagement of the housing blades and the first stage impeller.

Thus, the presented method for determining the width of the second stage b_2 makes it possible to reduce the effective power expended during operation of the vacuum pump and increase the speed of operation of two-stage liquid ring vacuum pumps.

The percentage of reduction :

of energy consumption by the modified design is 15-20%. The reduction of energy consumption is due to lower power consumption for the compression process, which is due to the described design implementations, as well as the refined method for calculating the width of the second stage

Conclusions.

The presented modified designs of liquid ring vacuum pumps can significantly reduce the costs of organizing a vacuum in technological processes of agricultural production. The technological indicators of the vacuum pump are directly affected by its design parameters, the optimal calculation method for which can provide a number of advantages. The presented method for determining the width of the second stage casing allows for a reduction in the power expended during operation and an increase in the speed of action (productivity) of the vacuum pump. This method is recommended for use in the design of the described improved designs of the liquid ring vacuum pump.

Conflict Of Interest

The authors declare no conflict of interest associated with this manuscript.

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