УДК 621.516

LIQUID RING VANE VACUUM PUMPS. TRENDS IN DEVELOPMENT OF VACUUM TECHNOLOGY

Yu.V. Rodionov

Department "Theory of Machines Mechanisms and Machine Parts", TSTU

Represented by a Member of the Editorial Board Professor Yu. V. Vorobyev

Key words and phrases: liquid ring vane vacuum pump; power; pump capacity; specific capacity; specific mass.

Abstract: The operating conditions of liquid ring vacuum pumps and factors which influence the vacuum treatment process efficiency have been considered. Trends in liquid ring vacuum pump designing allowing to build optimal models illustrated by the concrete example have been suggested.

Modern tendency to build machines must meet requirements of being universal, that is being available for the application in a wide range of characteristics with minimal energy consumption and being reliable in operation. The given requirements are realized at the design stage by using reliable and precise engineering calculating methods, by making standard design decisions, at the operation stage – by adjusting as required by operating conditions.

Vacuum pumps operating at suction pressures up to 0,1 kPa are used in chemical, textile, pharmaceutical, metallurgical, pulp and paper, food and other industries and in agriculture. Reciprocating, rotary vane and liquid ring vacuum pumps belong to this group of pumps. Liquid ring vacuum pumps offer advantages over rotary vane pumps, because they are simple in operation as this group does not require oil-lubricated pumps and special lubrication systems, all clearances are sealed with working fluid. The liquid ring pumps provide gas suction more evenly when compared to reciprocating vacuum pumps. Liquid ring vacuum pumps have lower operating noise level than other similar pumps.

Compression process in liquid ring vacuum pumps allows to pump out impermanent, igniting, highly explosive, polymerization gases and mixes, as well as gases with vapors, drop fluid and solid heterogeneous particles. Choice of working fluid provides pumping out of aggressive gases which do not allow to pollute them with oil vapors [4].

The main drawbacks of liquid ring vacuum pumps, as opposed to other positive displacement vacuum pumps, are low vacuum, that substantially reduces the field of application, and low efficiency.

Vacuum achieved by liquid ring pumps is limited by vapor pressure at the specific working fluid temperature in the suction zone. Back migration occurs from the surface of the liquid ring and can be determined [1]:

$$G^n = e^{-\frac{\sqrt{3}}{4}\sqrt{\mu^{\mathrm{f}} R^{\mathrm{f}} T^{\mathrm{f}}}\int \frac{F_{\mathrm{sur}}}{V_{\mathrm{c}}} dt} \left(C_1 + \frac{\sqrt{3}}{4} P_{\mathrm{s.v}} \sqrt{\frac{\mu^{\mathrm{f}}}{R^{\mathrm{f}} T^{\mathrm{f}}}} \int F_{\mathrm{sur}} e^{\frac{\sqrt{3}}{4}\sqrt{\mu^{\mathrm{f}} R^{\mathrm{f}} T^{\mathrm{f}}}\int \frac{F_{\mathrm{sur}}}{V_{\mathrm{c}}} dt} \right) dt, \qquad (1)$$

where μ^{f} – fluid viscosity, Pa·s; T^{f} – fluid temperature, K; F_{sur} – area of back migration surface, m^2; $P_{\text{s.v}}$ – pressure of saturated vapors, Pa; V_{c} – volume of working cell, m^3.

Therefore, it is possible to increase vacuum depth by changing working fluid properties which decrease the back migration and reduce the suction pressure or by reducing the back migration surface.

Lowering of efficiency is determined by great consumption of effective power and losses of pump capacity.

In the process of vacuum treatment effective power of a two-stage vacuum pump consists of effective power of the first and the second stages:

$$N_{e_p} = N_{e\text{I}_p} + N_{e\text{II}_p} . \tag{2}$$

Each summand of equation (2) for liquid ring vacuum pumps includes power consumed for compressing vapor-gas mixture – $N_{\text{com}i_p}$, shifting a liquid ring – $N_{\text{G}i_p}$, and power consumed for surmounting the friction in glands and bearings – $N_{\text{fr}i_p}$:

$$N_{ei_p} = N_{\text{com}i_p} + N_{\text{G}i_p} + N_{\text{fr}i_p} . \tag{3}$$

In its turn power consumed for shifting a liquid ring is used for shifting a liquid ring in the blade space – N_{bs_p} and in the bladeless space – $N_{\text{bs.s}_p}$:

$$N_{\text{G}i_p} = N_{\text{bs}i_p} + N_{\text{bs.s}i_p} . \tag{4}$$

At the initial operating conditions a single-stage pump is more effective as its compression power consumption is less and there is no need for the operation of the second stage which leads to the waste of energy for rotating a liquid ring in it (fig. 1).

Power consumed for rotating a liquid ring makes up the biggest part of the whole power needed for the operation of the pump of this type. The effectiveness of the operation of vacuum pumps is characterized by specific capacity of vacuum treatment determined:

$$N_{\text{sp.p}} = \frac{N_{e\text{I}_p} + N_{e\text{II}_p}}{S} , \tag{5}$$

where S – pump capacity , m^3/s.

Advanced models of pumps must have minimal appropriate values of $N_{\text{sp.p}}$ determined by fluid friction against the casing in the bladeless space.

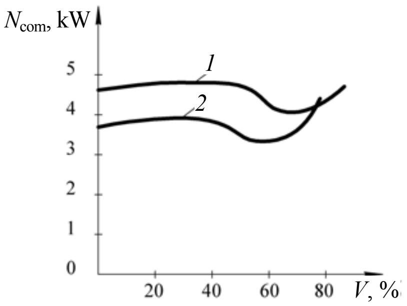


Fig. 1 Graphical representation of compression power consumption at different operating conditions of a liquid ring vacuum pump:
1 – two-stage pump;
2 – one-stage pump

The reduction in value of specific capacity is possible due to decrease in:

– compression power at initial operating conditions of vacuum treatment when an operating pump imitates a blast blower, at that it is enough to use the first stage only;

– fluid friction power against the casing achieved by reduction or elimination of velocity gradient along the liquid ring cross-section;

– the overall power for rotating a liquid ring determined by reduction of mass flow rate of working fluid up to absolutely necessary.

Pump capacity is determined by location and configuration of a liquid ring under real operating conditions [5]:

$$S = S_{\text{g}} \lambda_1 \lambda_2 , \tag{6}$$

where λ_1, λ_2 – pumping-out coefficient of the first and the second stages correspondingly; S_g – geometric pump capacity.

Geometric pump capacity is the product of rotation frequency and geometric volume and it depends on eccentricity, size of an impeller:

$$S_g = \pi r_2^2 b_0 \psi \left(1 - \nu^2\right) n, \tag{7}$$

where r_2 – external radius of an impeller, m; b_0 – width of an impeller, m; ψ – coefficient taking into account overloading of working volume with blades; ν – impeller boss radius to impeller external radius ratio; n – rotation frequency of an impeller, rev/min.

Numerous papers of Russian and foreign scientists [7 – 9], which contain the description of location and configuration, do not present the real situation. It is found out [3, 6], that a liquid ring changes its location and sizes depending on the operating conditions of a pump. Variable location of a liquid ring is the result of unstable equilibrium of liquid and gas phases and the quality of additional working fluid. The above mentioned fact makes us to immerse blades into fluid in lower diametrical position that excludes a slippage of the gas phase. It in its turn leads to decrease in working volume resulting in pump capacity reduction.

Besides working fluid which is necessary for formation of a liquid ring serving as a pump liquid piston, additional fluid is being constantly fed. Its amount is determined by the necessity of heat dissipation: compression of gas phase and fluid friction; sealing of end clearances; replenishment of a liquid ring because of fluid entrainment by the gas phase. Performance characteristics of a liquid ring vacuum pump are influenced by the quantity and feed zone of additional fluid [9].

Investigation of influence of pump capacity on pump efficiency results in the necessity of increasing this parameter due to:

– stabilization of geometry of a liquid ring;
– absolutely necessary feeding of additional working fluid;
– strict geometry and location of feed zone of additional working fluid.

In accordance with the above suggested ways of reduction of essential power and increase of pump capacity in order to eliminate the above mentioned drawbacks reducing the efficiency and to enlarge the field of application, keeping all advantages of liquid ring vacuum pumps, a model of a liquid ring vane vacuum pump has been developed at the department of "Theory of Machines Mechanisms and Machines Parts" of Tambov State Technical University (fig. 2).

The pump operates as follows: rotation of power shaft of pump casing *2* of the second stage due to of V-belt and friction drives makes to rotate housing *1*, at that a liquid ring is created by the centrifugal forces, this ring seals the bladeless space of the first stage and provide the pumping over of the gas phase from feed line *12* and intake line 8 to discharge port *10*; blades *5* passing through jointed seals 6 of casing *2* transfer the rotational effect to the impeller installed at stationary shaft *3* that leads to the pumping over of the gas phase in the second stage from inlet port *9* to discharge port *11* and exhaust line *13* and, thus, performing the two-stage vacuum treatment. For sealing of the inter-blade space of the first stage a liquid ring and seals *19* are used and casing rotation is realized by using bearings *17*, the second stage has jointed seals, seal *20* and bearing *18* for that purpose, this allows to run pumping over of the gas phase in the second stage without a liquid ring. The ultimate vacuum increase is made by decreasing the area of back migration by installation of flexible screen *23* and providing additional feeding out of suction zone *25*, *26*, *27*.

The suggested set-up represents an integration of two pumps for one length, that is the volume of impeller boss, is used. The first stage is the liquid ring stage, in which

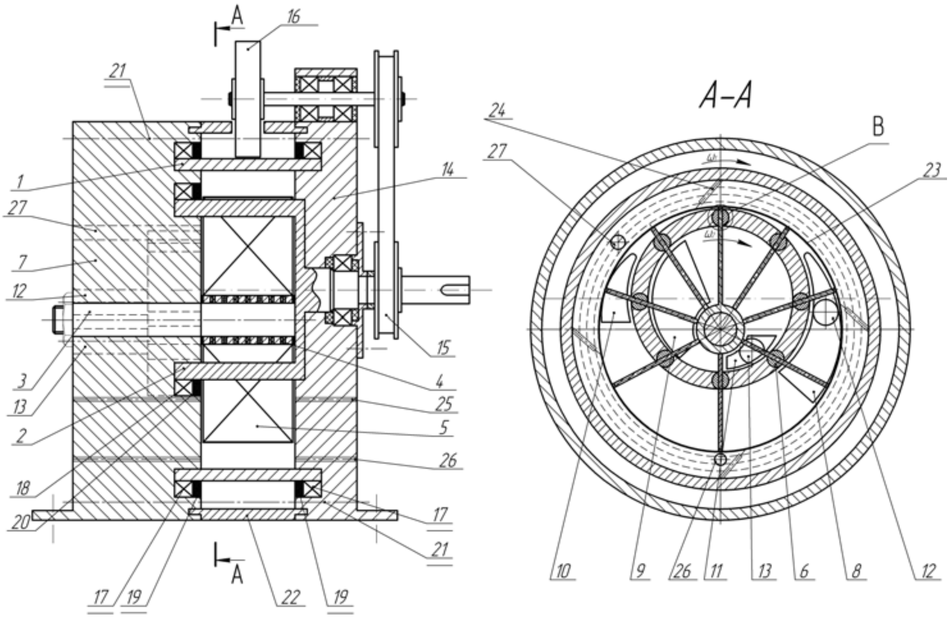


Fig. 2 Principal scheme of a liquid ring vane pump

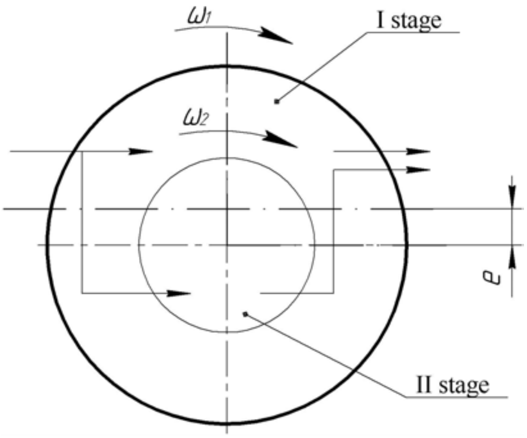
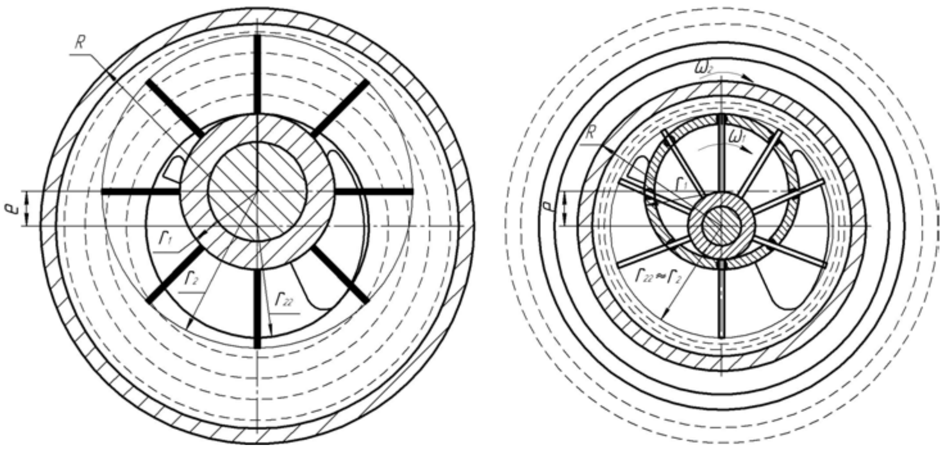


Fig. 3 The scheme of organization of vacuum treatment in series

fluid is necessary for sealing of end clearances and heat dissipation of gas phase compression that substantially decreases power consumption while rotating a liquid ring determined according to formula (2). The feeding of working fluid is provided at the direct sealing site of the edge clearances, i.e. in zone *26* behind the inlet port. The second stage is a vane vacuum pump. The operation of the pump is run according to the scheme of connection in series and it is possible to use only the first stage at the initial stages of vacuum treatment that reduces the specific capacity determined according to formula (5) (fig. 3) within the range and to connect the second stage for achieving deeper vacuum. Installation of flexible screen changes back migration area essentially decreasing the amount of back migration that allows to increase the ultimate vacuum achieved by this pump. Preliminary calculation of reduction in specific capacity according to formula (5) gives a 25 % win practically at all regimes of pump operation.



a) *b*)

Fig. 4 Comparative mass clearance scheme of pumps with equal pump capacity: *a* – liquid ring vacuum pump; *b* – liquid ring vane vacuum pump

The construction of liquid ring vane vacuum pumps, when compared to traditional ones, has lower value of specific mass due to combining stages, that is why the second factor will be specific mass

$$m_{\text{sp min}} = \frac{m}{S}, \tag{8}$$

where m – pump mass, kg.

Considering the specific mass factor with equal pump capacity and 25…30 % deeper vacuum the liquid ring vane vacuum pump design offers advantages over the analogous two stage liquid ring vacuum pump produced abroad (fig. 4).

Improvement in mass clearance characteristics eventually leads to reduction of the cost of the pump and vacuum treatment process.

In conclusion it is necessary to outline the following: the further application of principles increasing the efficiency of liquid ring vacuum pumps, suggested in this paper, will result in designing of the new group of vacuum pumps that features high operating and technical characteristics and fits each application from the standpoint of vacuum obtained.

References

1 Галич, В.П. Исследование рабочего процесса жидкостнокольцевых машин: дис. … канд. тех. наук / В.П. Галич. – Казань, 1979. – 162 с.

2 Никитин, Д.В. К вопросу о подаче дополнительной рабочей жидкости в жидкостнокольцевом вакуум-насосе / Д.В. Никитин, С.А. Редкозубов, Ю.В. Родионов // Качество науки – качество жизни: Сб. науч. статей. – Тамбов, 2006. – С. 90-92.

3 Родионов, Ю.В. Влияние конфигурации жидкостного кольца на рабочие параметры жидкостнокольцевого вакуумного насоса / Ю.В. Родионов, Ю.В. Воробьев, Д.В. Никитин, И.В. Шлыкова // Вестник ТГТУ. – Тамбов. – 2006. – Т. 12. – №1А. – С. 129-136.

4 Родионов, Ю.В. Обзор теоретических и экспериментальных исследований жидкостнокольцевых вакуум-насосов / Ю.В. Родионов, Ю.В. Воробьев // Фундаментальные и прикладные исследования, инновационные технологии профессиональное образование: сб. науч. статей. – Тамбов, 2006. – С. 71-76.

5 Родионов, Ю.В. Повышение эффективности эксплуатационных характеристик двухступенчатых жидкостнокольцевых вакуум-насосов: дис. … канд. тех. наук / Ю.В. Родионов. – Тамбов, 2000. – 135 с.

6 Родионов, Ю.В. Уравнение конфигурации жидкостного кольца для жидкостнокольцевых вакуум-насосов / Ю.В. Родионов, Д.В. Никитин, А.В. Волков // Глобальный научный потенциал: сб. науч. статей. – Тамбов, 2005. – С. 81-83.

7 Тетерюков, В.И. Ротационные вакуумные насосы и компрессоры с жидкостным поршнем / В.И. Тетерюков. – М.: Машиностроение, 1960. – 251 с.

8 Фролов, Е.С. Вакуумная техника / Е.С. Фролов, В.Е. Минайчев, А.Т. Александрова. – М.: Машиностроение, 1985. – 339 с.

9 Oury, F. Etude d’une Pompe a Anneau Liquide. – Revue universelle des mines, 1967. – №9. – P. 235-244.

Жидкостнокольцевые пластинчатые вакуум-насосы. Направление развития вакуумной техники

Ю.В. Родионов

Кафедра «Теория механизмов, машин и детали машин», ТГТУ

Ключевые слова и фразы: быстрота действия; жидкостнокольцевой пластинчатый вакуум-насос; удельная масса; удельная мощность.

Аннотация: Рассмотрены режимы работы жидкостнокольцевых вакуум-насосов и факторы, влияющие на эффективность процесса вакуумирования. Предложены направления в проектировании жидкостнокольцевых вакуум-насосов, позволяющие создать оптимальные образцы, проиллюстрированные на конкретном примере.

Flüssigkeitsringliche Plattenvakuumpumpen. Richtung der Entwicklung der Vakuumtechnik

Zusammenfassung: Es sind die Regimes der Arbeit der flüssigkeitsringlichen Vakuumpumpen und die Faktoren, die die Effektivität des Prozesses der Evakuierung beeinflussen, untersucht. Es sind die Richtungen in der Projektierung der flüssigkeitsringlichen Vakuumpumpen, die die optimalen auf dem konkreten Beispiel angebotenen Muster zu schaffen lassen vorgeschlagen.

Pompes annulaires à vide à liquide et à palettes. Orientation du développement du technique vidé

Résumé: Sont examinés les régimes du fonctionnement des pompes annulaires à vide à liquide ainsi que les facteurs qui influencent sur l’efficacité du processus du vidage. Sont proposées les orientations dans la conception des pompes annulaires à vide à liquide permettant de créer les modèles optimaux illustrés sur un exemple concret.