EFFECT OF THE PRESSURE PULSATION ON THE PERFORMANCE OF VORTEX TUBE

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Abstract. In this study is investigated the phenomenon of energy separation in a vortex tube with various systems of valve control. The influence of different geometrical construction of valve control is studied in detail with the method of dimensional analysis and with a coefficient of performance named “efficiency of temperature”.

Keywords: μ cold fraction; ηT efficiency of temperature; ΔTr cooling effect.

1. INTRODUCTION

The rather low efficiency of the vortex tube limits the area of rational usage of them. Thus, one of the main problems of the examiner is searching ways and methods of raising the efficiency of the vortex separation. A big number of researches have been made to show up the geometric relations of the structural elements’ dimensions. Others had as an aim the research of methods of action to the processes in the separation chamber.

The artificial brake operation of the vortex stream at the heated end of the separation chamber creates good conditions for generate an axial current straightened towards the diaphragm and so it allows the decrease of the separation chamber’s length. At the same time with this break operation, the radial gradient of the speed in the area of intensive power exchange between the vortex currents increases and it produces an increase of efficiency.

The pulsatory evacuation of the hot fraction increases the efficiency by intensifying the heat exchange between the gas and the chamber’s walls and because of the influence of the pulsations in the process of energetic exchange between the axial layer and the peripherical one.

2. THE EXPERIMENTAL STAND

The experimental plant used for the energetic and componential separation in the vortex tube is presented in fig.1.

3. THE ANALYSIS OF THE EXPERIMENTAL RESULTS

In the control valve’s case an original solution is adopte, which takes into account the experimental results of V.J.Metenin, S.A.Piralisvili, A.V.Moraskin, V.A.Visocinim. The control valve spherically articulated and equipped with attenuation carriers out an vibratory movement. This causes a maintaince of radial pulsatory...
movement and even an intensification of it based on the residual kinetic energy of the hot faction.

For the generalization of the appreciation of the vortex tube’s efficiency the \( \eta_T \) efficiency of temperature is used.

\[
\eta_T^* = \frac{\Delta T_r}{T_0 \left(1 - \frac{1}{k^*\beta} \right)}
\]

(1)

Where: \( \beta = \frac{p_0}{p_t} \) is the pressure release degree of the agent in the vortex tube

4. THE DIMENSIONAL ANALYSIS

The difficulties of the analytical of the energetic separation process do not allow the systematization of the trials. That is why the examination of the condition of respecting the similitude of the flow stays one of the perspective directions on the vortex engines study examination. By elaborating the heat exchange hypothesis in counterflow we admit that in adiabat vortex tubes the adimensional parameters are:

\[
k = \frac{c_p}{c_v} ; M = \frac{w}{c} ; \text{Pr} = \frac{\rho c_p v}{\lambda} ; \text{Re} = \frac{wd}{v}
\]

(2)

The cold fraction’s valve is given by the limit conditions. Because the heat transfer in the tube is conditioned by the agent’s turbulence and not by the current’s feature in the flow’s nucleus. In geometrically similar tubes, the transfer’s intensity depends a little on Re’s value. The influence can be noticed by Stanton criterion calculation: St=f(Re). Also the transfer’s intensity isn’t determined either by Pr’s value, which doesn’t influence the process’ feature of transfer into gases.

In experiments with geometrically similar tubes the values for k, \( \beta \), \( \mu \) and \( T_i^* \) are chosen arbitrarily ensuring the similitude of the processes. The invariability of the \( \eta_T \) “temperature efficiency” is the result of the analogy:

\[
\eta_T = f( k, \beta, \mu )
\]

(3)

In the absence of movement equations’ solvation, we use the dimensional analysis method. All variables which influence the separation effect make a function dependent on 11 adimensional invariables.

If the flow through the nozzle is at critic parameters, the diaphragm’s orifice is big enough (the pressure losses on the diaphragm can be neglected) if the gas is thermodynamically perfect and if we neglect its temperature variations on its ray, in the sections close to the admission nozzle we obtain:

\[
\Delta T_r = q_i^2 \varphi \left( \mu, \eta \right) / 2c_p
\]

(4)

This regime is characteristic for \( \mu \leq 0.25 \), that is for maximum temperature efficiency state.

To obtain a gasodynamic similitude with maximum energetic exchange efficiency, it is necessary and sufficient to keep the \( \frac{1}{\beta^2} \) criterion invariable. The constance in formula number 5 depends on the physical qualities of the agent, the absolute temperature and the agent’s density after diaphragm.

\[
\eta_T = \text{const. } \varphi \left( \frac{1}{\beta^2} \right)
\]

(5)

For the measuring of the experimental state it has been used as first criterion the “efficiency of temperature” of the vortex tube which takes into account the geometrical similitude through the agency of the \( \frac{1}{\beta^2} \) criterion invariable. The coefficient’s value, dependent on the agent’s characteristic, it’s thermodynamic parameters and the functioning state of the plant, has been experimentally established.

Fig.2 The efficiency of the vortex tube equipped with a fixed control system

Fig.3 The efficiency of the vortex tube equipped with a vibratory control system
\[ \eta_r = \left(0.455 + 0.282 \mu - 0.835 \mu^2\right) / \left(\bar{S} \beta\right)^{\frac{1}{2}} \] (6)

On the basis of the results of experimental study it has been determined the variation of the temperature efficiency (1) of the vortical separation process when the compressed agent’s pressure \( p_{o} \) varies in the 2÷10 bar limits and the \( \mu \) fraction in the 0.1÷0.85 limits. We find that while the \( \mu \) fraction increases the “temperature efficiency” decreases. The control system’s influence manifests especially in the case of vortex tubes which work at \( \mu = 0.2÷0.3 \) regime by emphasizing of the frigorific effect and a decrease of it for the upper values of \( \mu \).

If the nozzles surface is correlated with the compressed agent’s pressure and flowrate we find that the cold air fraction of the vortex generator influences a lot the “temperature efficiency” of it.

But, the vortex generator’s supply pressure doesn’t influence the efficiency, if the geometrical similitude, and the vortex tube’s efficiency characterised by a constant surface of the nozzles (fig.7) we find the followings:

The relation depends on the reference state the analysis is made (in this case the relation is unitary) \( \pi^* \)’s increase is accompanied by \( \Delta T_r \)’s increase and the maximum points correspond to lower and lower values for \( \mu_{opt} \)

at higher pressures than the reference state we find an increase of the ration with approximatively 10%, determined by the intensification of the heat exchange between the vortex currents and a sensitive increase of the losses caused by the irreversibilities in the nozzles.

at lower pressures than the reference state, the vortical separation’s efficiency fall of because of the vortical interaction looses.
5. CONCLUSION

For the maintenance of the geometrical similitude in the conditions of maximum temperature efficiency it is necessary and sufficient to keep unmodified \( S \beta^2 \) criterion, corresponding to the critic flowing state through the nozzles.

The fact that at the same time with the \( \beta \)'s increase the maximum decrease can be explained by the influence of the hydraulic resistance of the diaphragm (its diameter staying unmodified during the experiments) and by the increase of the losses caused by the irreversibilities in the nozzles.

The economy of the vortical separation process must be looked at not only from the vortex tube sight but also in correlation with the compressed gas source’s feature and the parameter which characterise it.

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