UDC 621.51. 004

M.P. Andriyishyn, PhD, K.I. Kapitanchuk., PhD, M.O. Pikul, V.V. Otroshchenko
(National Aviation University, Ukraine)

A study of the energy balance of main gas pipeline operating modes on its efficiency

A study of the efficiency of the main gas pipeline «Soyuz» in different modes with the corresponding daily productivity and the effect of compressor stations shutdowns were conducted. The dependence of specific energy of fuel gas on the energy of transported natural gas at the exit from the main gas pipeline and its productivity was obtained.

The efficiency of use of the gas transportation system (GTS) in the process of natural gas transportation over significant distances depends on many factors, in particular on the optimal operation of linear compressor stations (LCS), the coefficient of hydraulic resistance of linear sections of the pipeline, the amount and cost of fuel gas, etc.

The issue of natural gas transportation efficiency is particularly relevant during the transition of the Ukrainian gas industry to natural gas billing in energy units and the increase in the unit price of natural gas in world energy markets.

The purpose of this article is to study the influence of emergency stops of LCS and fuel gas volume changes on the efficiency of the main gas pipeline (MGP) during long-distance transportation of natural gas. The solution of this problem allows to determine the optimum mode parameters of the MGP operation in pumping a given gas volume in energy units at its minimum consumption.

A number of methods and studies are related to determining the cost effectiveness of the natural gas transportation process.

In studies [1, 2], mathematical models of MGP and LCS operation based on the summary characteristics of the corresponding type of superchargers were presented, which became the basis for further researches and calculations.

The influence of energy efficiency of fuel gas use on the choice of rational modes of operation of the GTS in the conditions of a market economy was investigated in work [3]. A technical and economic analysis of the efficiency of natural gas pumping in different modes was carried out. As a result, the dependence of gas transportation costs on the parameters of the operation mode was established.

In the article [4], the principles of forming mathematical models for selecting the rational modes of operation of complex GTS with shop compressor stations equipped with different types of gas pumping units (GPU) are given. The principle solutions that allow to formalize the objective function for choosing a rational mode of operation of the GTS in the conditions of its incomplete loading are outlined.

The authors of paper [5] proposed a set of mathematical models of objects and systems of gas pipeline transport adapted and intended for the systematic analysis of their non-stationary and stationary modes. The methodology for determining the energy efficiency of the use of resources and technologies and the implementation of energy-saving measures in the national economy and social sphere were developed.

Optimization of the GTS operating modes in the conditions of part-load operation has its own special approaches and implementation principles. Peculiarities of the optimization procedure concern expansion of permissible modes and the choice of technological schemes and equipment of GTS. In case of significant reduction of its capacity, exploitation is possible by reducing the number of working compressor stations or GPUs.

In the article [6], strategic directions and methods of optimizing modes and maintenance of GTS in conditions of partial loading were developed. In the paper [7], models of the functioning of individual parts of the system were built for operational control of the GTS operating mode: CS, linear sections, regulating and shut-off valves, etc. Authors proposed a one-dimensional description of gas transportation processes through the pipeline. At the same time, the gas flow in the channel is considered with constant parameters along the pipe cross-section: speed, temperature, pressure and density.

In the work [8], an assessment of the current state of natural gas transit by the Ukrainian GTS was carried out. The prerequisites for further reduction of GTS loading in the direction of Europe through the gas metering station Orlivka (southern direction), taking into account the construction of bypass gas pipelines were considered.

The methodology includes the calculation of gas physical properties according to its composition, gas compression, linear part, consumption of gas for the own needs of the CS and total power of GPU under the given technological limitations. According to the results of the optimization the graphical dependences of optimum rotor speed of superchargers on gas pipeline capacity, changes in power and pressure depending on gas pipeline capacity at operation of different combination of blowers were plotted. Recommendations on minimization of fuel gas consumption at compressor stations were given.

The effect of ambient air temperature on the GTU capacity, the possibility of using an expander-generator for power generation, preheating of air and gas entering the gas turbine for saving fuel were investigated in the article [9] in order to improve the efficiency of gas turbine units at CSs of MGP. A gas turbine scheme was developed, which includes air heating before the compressor, gas supply through the expander-generator and gas heating after it.

Since Ukraine acceded to the terms of the Energy Community Treaty and signed the Association Agreement with the European Union, the Ukrainian government has committed itself to the implementation of the Energy Community legislation in the energy sector and integration into European energy markets. One of the key aspects of the natural gas market reform is the introduction of the use of energy units for gas billing. Consequently, the authors of this article analyzed the efficiency of MGP operation in the process of long-distance natural gas transportation not in units of volume, but in units of energy.

Calculation of MGP operation modes was conducted in *Mathcad* software in order to determine its optimal operation mode [10, 11]. The main input data for calculating the CS operation mode are: natural gas flow rate, pressure at the inlet and outlet of the supercharger. The purpose of the calculation is to provide pumping of a given gas volume at minimum fuel gas consumption.

The most cost-effective modes are achieved at the maximum operating pressure in the pipeline, which ensures the minimum velocity of gas flow in the pipe and, therefore, the minimum hydraulic losses.

The second concept, which should be adhered to in the development of gas pipeline operation mode, is to ensure a given gas volume pumping with a minimum number of working machines. Approximation to the maximum value of polytrophic efficiency provides their full load, high efficiency, minimum wear and tear of supercharger fleet, savings of oil, power and materials.

It is also important to calculate the impact of shutdowns of CSs and individual units on gas pipeline operation mode. Shutdown of one of the intermediate stations causes changes in operation mode of MG as a whole, so there is a need to regulate speeds of superchargers or to stop separate GPUs to ensure its further operation. During shutdown of separate GPUs at CSs, two cases are possible: shutdown of one or several units working in parallel or shutdown of one supercharger from a group of GPUs working in series.

Shutdown of the unit operating in the parallel group at the intermediate compressor station will lead to a proportional decrease in its capacity, but the capacity of the other compressor stations will remain constant. As a consequence, the pressure at the outlet of the compressor station will decrease and the pressure at the inlet will increase.

During this process, the productivity of the compressor stations will gradually increase as the compression ratio decreases. The pressure in the sections between the previous stations will increase in this case. If the maximum pressure at the outlet of these CSs is reached, it will be necessary to reduce the speed of the operating units or to stop individual superchargers.

This research was carried out on the basis of the «Soyuz» MGP, D=1420 mm in diameter, L=1568,5 km in length and a design capacity of 75010,755 GW. The energy to move the gas flow along the pipeline is provided by twelve linear compressor stations, which include seven GPUs at each station, equipped with eighty-three stationary MS3002 and one aviation drive AI-336-2-10 with a total capacity of 840 MW and 4-8 and thirty-eight Demag 655P2.

Natural gas transported through the pipeline belongs to the second family of group H [12] with the following component composition: methane – 95%, ethane – 0,8%, propane – 1,2%, nitrogen – 1%, carbon dioxide – 2%. The density of natural gas at standard conditions (P = 1,01325 bar, T = 293,15 K) $\rho = 0{,}714$ kg/m^3, relative density by air $\Delta = 0.593$ with higher heat of combustion Hs = 10,304 kW/m^3 and lower – Hi = 9,293 kW/m^3. Wobbe number W=13,38 kW/m^3, gas constant R=503 MJ/kg K.

To study the efficiency of the operation of the MGP «Soyuz» at various modes with the corresponding daily output and the impact of the CS shutdown, a mathematical model was developed in the *Mathcad* software. Physical properties of natural gas, the specifics of the joint operation of the CS and the linear part of the MGP and the commercial accounting of gas in units of energy were taken into account in calculations.

The results of the study of the MGP operation efficiency on its capacity are presented in Table 1.

Table 1.

Dependence of the efficiency of the main gas pipeline on its capacity.

№	Daily capacity at the beginning of the pipeline Eg_{vh}, MW	Daily capacity at the end of the pipeline Eg_{vu}, MW	Fuel gas energy Epg_s^{**}, Epg_i^{***}, MW	Fuel gas specific energy ΔEpg	The efficiency of gas pipeline operation ηg %	GPU drive efficiency ηgpa %
1	32198,985	30762,718	1553,99** 1401,6***	0,05052*	95,191	16,83** 18,659***
2	34345,584	32650,8	1831** 1651***	0,0561*	94,69	16,86** 18,69***
3	36492,183	34462,903	2189,335** 1974,586***	0,06353*	94,027	16,82** 18,649***
4	39165,987	36945,105	2436,401** 2197,486***	0,06595*	93,813	16,822** 18,651***
5	40785,381	38331,252	2691,717** 2427,69***	0,07022*	93.439	16,82** 18,649***
6	42073,34	39347,805	2964,26** 2674***	0,07533*	92,994	16,835** 18,665***

* fuel gas specific energy is the ratio of fuel gas energy to the transported gas energy at the exit of the main gas pipeline $\Delta Epg = \frac{Epg_s^{**}}{Eg_{vu}}$.

** fuel gas energy and the efficiency of the GPU drive on the higher heat of combustion.

*** fuel gas energy and GPU's efficiency on lower heat of combustion

According to results of the study (Table 1), the increase in the capacity of the main gas pipeline leads to a significant increase in fuel gas. The specific energy spent on transporting a unit of energy increases from 0,051 at the end of the main pipeline capacity of 30762,718 MW to 0,075 at the end of the main pipeline capacity of 39347.805 MW. With an increase of transported natural gas by 27,9%, the fuel gas volume will increase by 47,1%.

Interpolating the curve of dependence of fuel gas specific energy ΔEpg on transported natural gas energy at the outlet of the main pipeline Eg_{vu}, an estimated dependence describing fuel gas energy costs for transportation of energy unit through the «Soyuz» MGP was obtained $\Delta Epg = 1{,}4036e^{0.017Eg_{vu}}$.

Summary

The efficiency of operation of the «Soyuz» MGP at different modes with the corresponding daily capacity and the influence of compressor station shutdowns were investigated. The dependence of fuel gas specific energy on natural gas transported energy at the outlet of the main gas pipeline on its performance was obtained. If natural gas transportation increases by 27,9%, fuel gas volume will increase by 47,1%.

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