Justification of the choice of pump drive for pumping stations of main pipelines, taking into account the principles of energy and economic efficiency

A G Zakirzakov and Yu D Zemenkov
Tyumen Industrial University, 38, Volodarskiy str., Tyumen, 625000, Russia
E-mail: zakirzakovag@tyuiu.ru

Abstract. One of the key conditions for the dynamic development of oil trunk transportation is to reduce the cost of pumping whose important component is energy costs. Energy transportation costs can be reduced by choosing an optimal type of the drive for pumping stations during construction and reconstruction of existing oil pipelines. An alternative to the electric drive can be a gas turbine. In foreign countries, oil is transported through the gas turbine pump drive. In the conditions of changes in energy prices, it is necessary to develop a method for comparing types of drives of the pump unit, each of which has its own advantages and disadvantages, in order to compare factors such as technical characteristics of the drive, distance from power sources, and the availability of a gas supply system, etc. Development of the pump drive selection methodology that takes into account international and Russian experience is relevant and will allow us to justify the choice of aggregate drives when designing pump stations.

1. Introduction
The basis for increasing the economic efficiency of each country is the rational use of production resources, material and energy resources.

A series of world energy crises of the 1970s, as well as the embargo on oil from the Arab countries, which caused an increase in energy prices, prompted the world community to reduce the dependence of the economy on energy consumption. As a result, the energy conservation policy has become one of the solutions to the problem of economic efficiency. The states began to stimulate projects on energy conservation, including the efficiency of consumption of fuel and energy resources.

Huge material costs associated with the construction and operation of trunk pipelines, as well as the energy costs of oil and gas transportation necessitate a careful approach to the reliability of the trunk oil and gas pipeline systems.

2. Results
The calculations of the ratio of reduced costs of energy when using a gas turbine and an electric drive made by the Russian State University of Oil and Gas (Moscow) helped to determine the ratios of prices for fuel gas and electricity (Figure 1), as well as to build diagrams that determine the area of rational use of these drives, taking into account the ratio of energy prices and efficiency of a gas turbine engine. [3-7]
The data obtained show a critical ratio of electricity and fuel gas prices under the rational use of gas turbine and electric drives depending on their efficiency. It can be concluded that the gas turbine drive is more preferable at compressor stations of gas mains.

To transport oil, electric motors of main pumping units are widely used. The electric drive used on main pumps has many advantages, however its use entails additional costs associated with the use of electricity. In addition to direct additional financial costs to compensate for the increase in process for 1 kW * hour of electricity, it is necessary to take into account the cost of its supply. The construction of power lines for oil pipelines causes a number of difficulties. Firstly, the construction of power lines requires significant capital expenditures, because they lie in inaccessible sparsely populated areas; secondly, given the length of the conductive lines, which can reach several thousand kilometers, there are significant losses of electricity.

At the initial stage of development of oil pipeline transport, the choice of the type of drive for pumps was not difficult. There was only one source of energy - combustion energy of pumped products. However, in future, for geographically distant regions and regions with difficult climatic and geographical conditions, the electric drive began to be used. This was largely due to the electrification of the country. Over time, the electric drive of the main pumps has become virtually uncontested. The modern design system leaves no choice for a design engineer. Not all the factors that determine the choice may not be relevant. Technical solutions are different in different regions.

An alternative to the electric drive is a gas turbine. Oil is transported through the gas turbine pump drive abroad. A good example is the Transalyaskin trunk oil pipeline. CPC uses Siemens gas turbines (in regions with the undeveloped energy infrastructure).

Given the cost of construction of power lines and energy losses, the cost of transmission of 150 MW per 400 km is half the cost of building a thermal power plant of the same capacity.

The use of gas turbines is determined by the fact that a significant part of the main oil pipelines passes through the underdeveloped areas and areas located at considerable distances from the energy systems.

Single-shaft and twin-shaft aircraft, marine and industrial gas turbine engines with intermediate cooling of cyclic air, regeneration and utilization of heat of exhaust gases are used to drive pumps of the main oil pipelines. For these engines, it is possible to use various types of fuel, including prepared crude oil. To increase the efficiency, the fuel system and gas turbine engine automation are sometimes
designed taking into account the use of two types of fuel - liquid and gaseous ones. The heat of exhaust gases can be used for household needs. Therefore, the efficiency of such gas turbine units reaches 31–35%, while the efficiency of aircraft and ship power plants rarely exceeds 23–25%.

When choosing the drive, it is necessary to take into account conditions of the construction area. It should be borne in mind that in order to improve the structure of the energy balance, it is desirable to use the drive which provides higher efficiency and runs on electricity generated by the least scarce and qualified fuel.

By comparing the efficiency of electric drive and gas turbine drives, it is possible to determine the most appropriate drive for the pump unit.

The efficiency of the electric drive is expressed as follows:

\[ \eta_{pp} = \eta_{ac} \times \eta_{tr} \times \eta_{ee} \times \eta_{p}; \]  

where \( \eta_{pp} \) – Efficiency generating power plants in the power system; \( \eta_{tr} \) – Power transmission efficiency; \( \eta_{ee} \) – engine efficiency; \( \eta_{p} \) – Gearbox efficiency.

Drive applications are justified if the conditions are met

\[ \eta_{pp} > \eta_{gt} \quad \text{or} \quad \eta_{pp} \times \eta_{tr} \times \eta_{ee} \times \eta_{p} > \eta_{gt} \]  

where \( \eta_{gt} \) – Gas turbine drive efficiency.

In order to determine the appropriate use of an electric drive, one can obtain expressions for comparing the efficiency of a power plant and a gas turbine:

\[ \eta_{pp} = \frac{\eta_{gt}}{\eta_{tr} \eta_{ee} \eta_{p}}; \]

If

\[ \eta_{tr} = 0.85; \eta_{ee} = 0.978; \eta_{p} = 0.985; \]

\[ \eta_{pp} > \frac{\eta_{gt}}{0.85 \times 0.978 \times 0.985} = \frac{\eta_{gt}}{0.819} = 1.22 \eta_{gt} \]

For the GTK-25, the efficiency is 0.29.

Therefore, if \( \eta_{pp} > 1.22 \times 0.29 = 0.354 \), the use of an electric drive is most appropriate.

The efficiency of gas turbine plants can be significantly increased by using heat of the exhaust gases (by-products).

3. Discussion

When using gas turbine units, the issue of fuel used is crucial. It is most advisable to use a pumped product as fuel for engines. Petroleum products such as kerosene, gasoline, diesel fuel correspond to the requirements for gas turbine fuel. However, in oil pipelines, the use of kerosene or diesel fuel for gas turbine engines is not economically feasible due to the high cost and difficulty of delivery. In cases where a gas pipeline is installed parallel to the pipeline, it is very efficient to use natural gas as fuel. When using the pumped crude oil as fuel, vanadium corrosion occurs on the parts of the combustion chamber and turbine. At high temperatures, corrosion develops rapidly, which leads to a sharp reduction in engine life. The use of special additives, washing oil with special aqueous solutions, limiting the initial temperature of gases to 650 ° C helps to slow down the corrosion process and clog the engine’s gas-air path.

Oil should be prepared by separation or distillation methods or using additives. An example of oil preparation is the use of block distillation units of a column type. After oil rectification, 25-30% of light fractions are obtained, and the remainder (fuel oil) is pumped into the oil pipeline. The use of such a column is economically viable in areas which are remote from power sources and oil refineries, since the cost of the resulting fuel for gas turbine plants is half that imported.

The dependencies between the main operating parameters of the electric motor and pump are widely studied. In order to determine the relationship between the main operating parameters of gas
turbines, the characteristics of various gas turbine engines were studied.

The rotational speed of a free turbine is independent of its throughput, which allows us to maintain pressure, outlet temperature, and air flow. Since the gas turbine works in one mode, the fuel consumption remains unchanged. There is a dependence of the main parameters of the turbine on the rotational speed of a free turbine. It is due to changes in the efficiency of a free turbine at different rotational speeds of the blades and constant adiabatic operation of the turbine. In such cases, there is a maximum relationship between power of the gas turbine of a free turbine and speed.

To determine the dependencies of the main parameters, we analyzed characteristics of both Russian and foreign gas turbine engines and experimental data:

\[
\bar{N} = \frac{N_p}{N_{nom}}; \quad \bar{G} = \frac{G}{G_{nom}}; \quad \bar{n} = \frac{n_p}{n_{nom}};
\]

An analysis of performance of the gas turbine engine allowed for the conclusion that for each value of turbine power, there are optimal values of the number of its revolutions. After analyzing the turbine speed at the peak of power, the optimal mode curve was created (Figure 2).

![Figure 2. The zone of optimal modes of the power turbine](image)

4. Conclusion

Given the efficiency of the turbine engine, the zone of optimal use of the gas turbine engine was calculated.

Having analyzed the existing pipeline transport systems and equipment of the main pumping stations and compared various drives, we can conclude that the electric drive used in 98% of cases is not alternative. The choice between different types of pump drives can be determined depending on the territorial location of the oil pumping station. In those regions where electricity is not expensive, an electric drive can be more economical than a gas turbine one. If it is necessary to change the operating mode of the pumping unit, thanks to the more economical method, the main pump driven by a gas turbine will be preferable.

In conditions of uneven oil supply, the use of a power turbine as a drive of main pumps can compete with an electric motor, and the optimum mode will save fuel gas.

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