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Research on Heat Economy of Drive Scheme for Generator Boiler Feed Pump

Yanjie Song [a], Zhijun Jia[b], Guojun Zhang [a]

[a] Department of Mechatronic Engineering, Inner Mongolia Vocational College of Chemical Engineering, Hohhot 010070, China
[b] Inner Mongolia Jinglong Electric Power Generation Co., Ltd., Ulanqab,012100, China
yanjiesong7742@163.com

The purpose of this study is to improve the heat economy of generator-unit boiler feed pump (BFP) drive and promote the driving effect of BFP. To this end, this paper studies the heat economy of generator's BFP drive. A large-scale coal-fired thermal power generating unit was taken as an example. Then, with reference to the current situation of each link in the feed pump drive chain, modern driving technology was applied, and the mathematical model of the drive scheme was established using the fixed flow analysis method to perform the calculation for specific case. The study found that for the BFP of the 600MW unit, the net powers are sorted by size in the following: traditional electric pump scheme < steam pump scheme < high-efficiency fluid coupling scheme < frequency conversion scheme < spindle scheme. Therefore, among the five drive schemes, the spindle drive scheme has the least links in the energy transfer process, so its heat economy is the best.

1. Introduction

China's thermal power plants are high-energy-consuming enterprises, with low utilization rate of electrical energy, which is inconsistent with the development trend of energy-saving and emission reduction. Boiler feed pumps (BFPs) need to consume mechanical work during operation and consume a lot of energy. Under the condition that the single unit capacity and steam parameters of generator unit in thermal power plant increase, the heat economy of the enterprise has undergone certain changes, and the power consumption of the BFP group has also increased.

The application of scientific and effective drive schemes in thermal power units can further reduce the energy consumption of thermal power plants and save resources. So, it plays a positive role in the daily operation of thermal power units and the development of enterprises. Based on this, with reference to the current situation of each link in the feed pump drive chain, modern driving technology was applied, and the mathematical model of the drive scheme was established using the fixed flow analysis method to perform the calculation for specific case.

2. Literature review

In terms of the driving scheme of feed water pump in power plant, because of the difference in working characteristics of different types of generating units and the difference in understanding and application of steam pump scheme and electric pump scheme, the factors of comprehensive safety and economy are described as follows:

Ahmadi et al. pointed out that China's thermal power units would continue to maintain a large scale for a long time, which was the backbone of China's generating units. However, the overall efficiency of thermal power units was not high, and the energy-saving potential of thermal power units could be tapped from various aspects. One of the energy-saving measures was to improve the efficiency of boiler feed water pumps, especially under low load (Ahmadi et al., 2017). Gao et al. pointed out that a small part of nuclear power units were full-speed steam turbines. The fuel cost was relatively low in nuclear power units, but the exhaust area of full-speed units was limited, the last stage blades cannot be too long, so, in order to control the length of shafting, the number of low-pressure cylinders should not be more than three. As a result, in full-speed

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nuclear power units, steam-driven feed water pumps were preferred. Some steam could be extracted from the main engine to drive small steam turbines to reduce the amount of steam entering the low-pressure cylinder (Gao et al., 2016). Powell et al. pointed out that large capacity air-cooled units should be built in coal-rich and water-scarce areas in Northwest China to save precious water resources. In air-cooled units with large and small units, not only the exhaust pressure was higher than that of wet-cooled units, but also the exhaust pressure varied greatly with the changes of ambient temperature (day and night, and seasons), ambient wind direction and wind speed. The back pressure in normal operation was only 10-15kPa, which could generally fluctuate to 30-40kPa and reached 60kPa at most (Powell et al., 2017). Yingjian et al. pointed out that the feed water pumps directly adopted air cooling or install air-cooled condensers separately. The available evapotranspiration of steam from small turbines was not only small, but also changed frequently and varied greatly, which had a great impact on the safe, economic and reliable operation of small turbines and would be difficult to achieve the reliability of safe operation. Therefore, the electric pump scheme should be adopted (Yingjian et al., 2016). Mrzljak et al. pointed out that if the wet-cooling conditions of small units could be met in some areas, steam pumps could be considered. For example, a supercritical air-cooled unit of Huadian Ningxia Power Generation Co., Ltd. (2X1000MW), used steam pumps and wet-cooled two small steam turbines. Two steam pumps were also used in a 600MW power plant in Inner Mongolia, which was put into operation in July 2005. However, the use of wet cooling alone in the mini-computer required a cooling pad and an increase in circulating water pumps. The system was complex, there were many auxiliary devices, and the investment was large (Mrzljak et al., 2017). Pawlak held that large-scale heating units with high parameters and large capacity in Western and Northern China had gradually been put into operation. In fact, the heating load of large-scale units was often changing, and the heating load and electric load could not be synchronized, so the use of steam pumps would easily lead to the incompatible conflict between the small steam turbine extraction pressure and the heating adjustment extraction pressure, which was often irreconcilable. Thus, the electric feed water pump was used in the feed water pump of the large heating unit (Pawlak, 2018). Barm et al. pointed out that the steam pump scheme was used for some large heating units, but the high quality steam used for small unit extraction was actually unfavourable to the thermal economy of the units (Barma et al., 2017). Chen et al. pointed out that on the surface, the power supply could be increased by the steam-driven mode. There were many links in the energy conversion of the electric mode, more power consumption and higher auxiliary power consumption. But in fact, the internal efficiency of the domestic small steam turbines was much lower than that of the low-pressure cylinder of the main engine, which led to more energy consumed by the steam-driven mode. The heat energy consumed by the steam-driven mode was not included in the factory, so there was an illusion that the low power consumption was low and economic performance was good (Chen et al., 2017). Wei et al. pointed out that the feed-water pump driving scheme of 300 units was more economical than that of steam pumps. The main reason was that the internal efficiency of domestic small steam turbines was lower at present. In the future, even if the internal efficiency of small steam turbines is increased to the same or even slightly higher than that of electric ones, the investment of electric devices is low, and the system is simple, it is flexible and reliable, and has obvious advantages compared with the steam mode (Wei et al., 2015). Zhai et al. pointed out that the adiabatic reduction of steam from the inlet of small steam turbine to the exhaust outlet was equal to the adiabatic reduction from the exhaust outlet to the exhaust outlet of main engine. In fact, the pressure drop and heat dissipation loss (i.e. pipe efficiency) of the pipeline and valve from the main exhaust outlet to the entrance of small steam turbine were neglected, as well as the exhaust of small steam turbine to the main condensation (300MW unit exhaust steam into the main condenser), which was not consistent with the actual operation. These two links could not be neglected in the comparison of thermal economy between the electric pump scheme and the steam pump scheme (Zhai et al., 2016).

In summary, the above research work mainly focuses on the research of feed water pump drive scheme in existing power plants, which mainly involves the implementation of some schemes, and the advantages and disadvantages of the schemes, but lacks of research on the thermal economy of its units. Therefore, based on the above research status, the influence of different driving schemes of boiler feed pump on thermal economy of generating units is mainly studied. Firstly, the principle and basic method are introduced, and then a typical 600MW unit in a manufacturer is selected for case analysis. The results show that the spindle drive scheme is the least in the energy transfer link, and its thermal economy is the best.

3. Principles and methods

The steam-powered feed pump was taken as the benchmark for the five drive schemes. In the physical model establishing process for various drive schemes, the specific efficiency value of each energy transmission link is undetermined temporarily, while the mathematical model is used instead. After establishing the physical

model, the mathematical model is also made. The specific difference for the same unit under different loads lies in the efficiency of each energy transmission link, and the specific values will be different.
Figure1 shows the physical model established by the steam pump scheme. In the traditional steam pump scheme, low-pressure steam is drawn from a large machine to a small steam turbine, which then drives the feed pump at a variable speed. For the 300MW and 600MW units, the steam extraction of small steam turbine is actually steam exhausting of intermediate pressure cylinder; that of the 1000MW unit is steam exhaustion of medium pressure cylinder. When the physical model is established, the feed pump unit is set to be typical 2*50% capacity. 100% capacity feed pump set also exists, but it's too rare to be used in the physical model. The two small turbines exhaust steams into the condenser of large turbine, since the condenser is not separately set for them. The front pump is driven directly by a common motor with a 6kV or l0kV power supply. Due to the characteristics of the steam pump, there must be a lubricating oil system. To ensure its normal operation, the AC lubricating oil pump and the AC exhaust fan must run accordingly. Therefore, the motor of the AC lubricating oil pump and the fuel tank exhaust fan consumes relevant power, which shall be listed in the calculation.

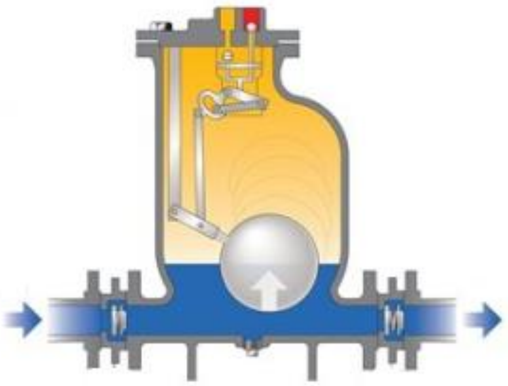

Figure 1: Physical model of the steam pump scheme

The physical model of the high- efficiency fluid coupling scheme is similar to the traditional maths model of the electric pump scheme. The main difference is that the efficiency of the high-efficiency fluid coupling is different from that of the conventional one (in this scheme, a high-efficiency motor is also used). For the conventional fluid coupling, the efficiency is directly proportional to the slip frequency. So, when the workload is lowered, the efficiency is also drastically reduced.
The modern large-scale frequency drive scheme can flexibly adopt the 1*100% scheme, 2*50% scheme, and 3*35% scheme when establishing the physical model. Here, for comparison, the feed pump unit is still considered to be the typical 2*50% configuration, as shown in the Figure2-5. In the frequency conversion scheme, feed pump and the front pump are both driven by the same motor. In order to improve the energy utilization level, the feed pump is directly driven by the high-speed motor. The front pump drives the feed pump through a reduction gear, and the reduction gear can be set to 3: 1; the existing high-speed motor can reach 7200ipm, fully meeting the speed requirements of the feed pump; the speed adjustment depends on the simultaneous changes of inverter voltage and current frequency; the inverter power supply is taken from the high-voltage factory.
In the spindle drive scheme, the feed pump is directly driven by the main engine. Since the main engine speed is constant at 3000 rpm, the speed must be adjusted. In the physical model, the high-efficiency fluid coupling speed should be regulated, because the engine is connected to feed pump on the high-voltage cylinder side, and only one interface can be provided for structural reasons, otherwise, in 300MW, 600MW, 1000MW units (basically all single-axis steam turbines) more axial sizes shall be increased (in the 1000MW unit by certain steam turbine manufacturer, the span of the steam turbine is only 27m, and combined with the extremely simplified structure of the front box, it has sufficient advantages to adopt the spindle drive scheme). Therefore, it is advantageous to use a 100% capacity feed pump in the spindle drive scheme.
At present, the newly built 600MW units are mainly supercritical units, as shown in Table 1. In the subsequent calculation, 600MW typical unit of one certain manufacturing plant was selected for case analysis.

Table 1: Comparison table of typical 600MW units of each manufacturer

		Unit form	Final blade height
1	N600-24. 2/566/566	Supercritical, one intermediate reheat, three cylinders, four exhaust steam, condensing	1050mm
2	CLN600-24.2/566/566	Supercritical, one intermediate reheat, three cylinders, four exhaust steam, condensing	1029mm
3	N600-24.2/566/566	Supercritical, one intermediate reheat, three cylinders, four exhaust steam, condensing	1016mm

The technical parameters of one typical 600MW supercritical unit are shown in Table 2.

Table 2: Main technical parameters of a 600MW unit

Model	N600-24.2/566/566
Type	Supercritical, one intermediate reheat, three cylinders , four exhaust steam, condensing
TRL	600MW
TMCR	636.585 MW
Maximum power	663.107 MW
Performance guarantee working condition heat consumption	7515kj/KW.h

Due to the lack of the unit's engine efficiency curve, the low-pressure cylinder efficiency curves of the typical 300MW and l000MW units were comprehensively adopted in the variable working condition, to obtain the low-pressure cylinder efficiency curve of the 600MW unit, as shown in Figure 2.

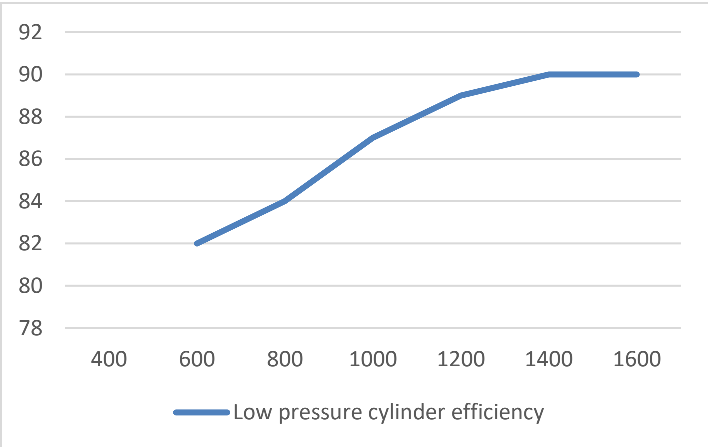

Figure 2: Low-voltage cylinder efficiency diagram of a 600MW unit in a factory

Table 3: Pre-pump technical parameters

project	specifications	project	specifications
model	HZB253-640	Head	142.3m
Rated speed	1490rpm	Limited Data	1017.67t/h
Minimum flow	250t/h	Maximum flow	1044t/h
Outlet pressure	2.34MPa	Rated speed	1490 rpm

The power of the small steam turbine reached 11.138MW, which was higher than the 6MW capacity of the 300 MW unit, with the improved efficiency. In the steam pump scheme for small turbines, field data of AC lubricating oil pump motor current 41.6A, and AC lubricating oil pump motor voltage is 380V; exhaust fan motor current field data is 0.6A, its motor voltage is 380v, and the power factor of the efficiency motor and the exhaust fan motor is 0.9; the efficiency of the high and low voltage station service power transformer is 98%, and the main transformer efficiency is 99%. The mechanical efficiency for reach coupling connection is 99%. Table 3 lists the technical parameters of the front pump.

4. Results and analysis

According to the method provided above, the efficiency characteristics of the five driving schemes were analysed. Then, the specific values were set, to obtain the net powers of the five driving schemes for the 600MW typical unit boiler feed pump. Table 4 shows the comparison table (MW).

Table 4: Comparison Table of Five Schemes for 600MW Unit

Project	100% load	75% load	50% load	30% load
N_{net}^{pump}	593.05	444.69	296.28	177.50
N_{gross}	620.24	462.55	306.12	183.13
$N_{gross}^{\mathrm{Trans}}$	592.01	442.67	294.77	176.38
$N_{gross}^{\mathrm{high-voltage}}$	593.25	444.98	296.74	177.67
$N_{gross}^{\mathrm{spindle}}$	594.71	446.70	297.78	178.44

It can be seen from the table that, similar to the 300MW typical unit, the net powers of the five driving schemes for the 600MW unit boiler feed pump is ordered by size: traditional electric pump scheme < steam pump scheme < high efficiency liquid couple/fluid coupling scheme < frequency conversion scheme < spindle scheme. Although the spindle scheme has a slightly lower net power than the frequency conversion scheme under 30% load, the spindle scheme can still be considered to be superior to the frequency conversion scheme, because the range of the variable working condition during normal unit operation is 50%-100%. Moreover, in the spindle scheme, if the front pump with 100% capacity also participates in variable frequency speed regulation, that is, lowering the front pump speed under low load, its net power will be still higher than the frequency conversion scheme even under 30% load.
It indicates that under the current new conditions, the high-efficiency fluid coupling scheme has more net power than the mainstream steam pump scheme in China at present, because of the heat economy, and simple and easy operation of the high-efficiency fluid coupling scheme, so, as a whole, it is superior to the steam pump scheme. Among the five feed pump drive schemes, the spindle drive solution has the least links in the energy transfer process, so its heat economy is the best.

5. Conclusions

Boiler feed pumps play an important role in the thermal economic cycle driven by pumps. More research has been done on the traditional and new drive schemes. Moreover, the difference in the boiler feed pump drive schemes will also result in good or bad heat economy. This influence on the heat economy will also increase with the increase of the unit capacity. In order to overcome the shortcomings of previous research on the thermal conductivity of the boiler feed pump drive scheme, the constant flow calculation method was introduced, which can systematically compare the heat economy of various boiler feed pump drive schemes. It is assumed that the parameters such as steam turbine inlet steam parameters and flow rate etc. are unchanged, that is, under the condition that the boiler coal consumption is constant, only the feed pump drive scheme is changed, and then the net power of various schemes are compared. For the boiler feed pump drive scheme with large net power, the standard coal consumption of the power supply is low. This can systematically reveal the heat economy of various driving schemes with great operability. According to the results, the steam pump scheme is no longer the optimal solution; among the five feed pump drive schemes, the spindle drive scheme has the least energy transfer process, so its heat economy is the best.
The heat economy of the new electric pump scheme is undoubtedly better than the steam pump scheme. However, when the power plant chooses the boiler feed pump, the heat economy is often not the only indicator, and the initial investment cost, civil construction cost, maintenance, major and minor repair costs

and whether the investment payback period is reasonable, etc. should also be considered, Although the spindle drive scheme has great advantages, it has a certain influence on the layout and operation of the main engine. Therefore, it should be further studied on how to overcome the adverse effects of the spindle drive scheme and achieve its excellent heat economy.

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