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Experimental Study on Feasibility of Roots-steam Generator

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Abstract: Waste heat recovery is an important way to improve the energy utilization efficiency and protect the environment. Waste heat power generation is one of the ways. In this paper a new power generation device that different from the screw expanding power generation and Organic Rankine cycle power generation named Roots-steam generator is designed to use the low-pressure saturated steam that pressure below 1 MPa and temperature below 200°C. One 100 Kw (Kilowatt) Roots-steam generator was designed to do the related experiment and the results show that the Roots-steam generator can use the steam that pressure is less than 0.3 MPa, flow less than 0.15 t/h(tons per hour) to generate electricity. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: Waste heat recovery, Roots blower, Steam generation, Heat recovery steam, PID.

1. Introduction

Energy-saving and environmental protection is a contemporary topic of global concern. Using waste heat generating electricity [1] is a way of reuse the primary energy, has been regarded as an important research direction of energy saving and environmental protection [2, 3]. At present, the waste heat recovery in small scale is mainly using the screw expander, smaller and unstable scale of waste heat recovery mainly using the technology of Organic Rankine cycle power generation [4-6]. Years of study found that there were many shortcomings in the presence of the screw expander power generation and organic Rankine cycle power generation technology. For example the screw rotor, used in the above generation technology, was very difficult in processing and manufacturing. There were other problems such as bearing lubrication is poor, easy to wear, poor sealing and so on. All factors make the use of low-quality-steam in small enterprises is impossible. At the same time, most of the waste-heat-steam that emptied by enterprises also can’t meet the lowest requirements of power generation equipment. Technology of heat steam recovery is very complex and its high cost may be the reason why they were not used widely [7-9].

In order to recover the waste-heat-steam that small and medium-sized enterprises emitted, author found one simple and low-cost technique. After the innovation and optimization, the Roots blower can meet those low quality heat recovery requirements. This paper summarizes the test: the experimental study on feasibility of Roots steam generator technology.

2. Roots-steam Generator Model Design

2.1. Roots Blower Model

Roots blower is volume blower [10]. The volume of conveyed air is proportion to the number of revolutions. When clover-type impeller rotating every circle, the two impellers will suction and exhaust for three times. Roots blower has small gas pulsation, vibration and low noise [11, 12]. In the blower, the two impellers and the ellipsoidal shell and the two impellers themselves keep a tiny gap. By the driving of the synchronous gear, the wind was transported from the blower inlet housing wall rim to the air vents [13, 14]. The work principle of clover Roots blower was shown in Fig. 1.

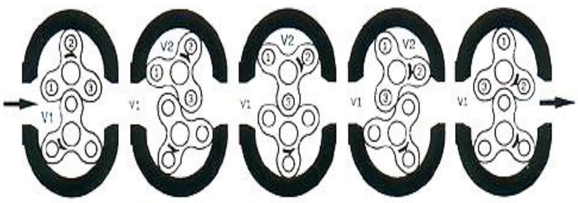


Fig. 1. The work principle of clover Roots blower diagram.

2.2. Roots-steam Generator Principle

According to the working principle of Roots blower shown in Fig. 1, assuming a certain pressure liquid or gas or both through the air inlet of Roots blower (Fig. 1 left), when the pressure of air outlet of Roots blower (Fig. 1 right) is less than the air inlet, medium will be expanded in the housing to drive the impeller rotated in a clockwise direction to generate kinetic energy, and Roots blower can be regarded as an expansion of the power machine [15].

Based on the above assumptions, one 100 Kw roots-steam generator was designed and its three-dimensional model shown in Fig. 2 [16].

3. Verification Test

In order to verify the Roots-steam generator can work at low pressure and unstable saturated steam, experiments are needed and the generator system model needs to continue to optimize:

1) Electric proportional control valve installed in the steam inlet;

2) Encoder installed on the shaft end of the generator;

3) Manual control valve installed before the electric proportional control valve;

4) Electromagnetic flowmeter installed on the inlet pipeline before the manual control valve;

5) The thermometer, pressure gauge is arranged between the electromagnetic flowmeter and the manual control valve;

The Roots-steam generator's three-dimensional model and photo are shown in Fig. 2 and Fig. 3. In the Fig. 2 there are: 1 – The control system, 2 – generator, 3 – Roots blower, 4 – electric proportional control valve, 5 – manual control valve, 6 – pressure gauge, 7 – thermometer, 8 – electromagnetic flowmeter, 9 – cooling fan, 10 – damping base, 11 – encoder.

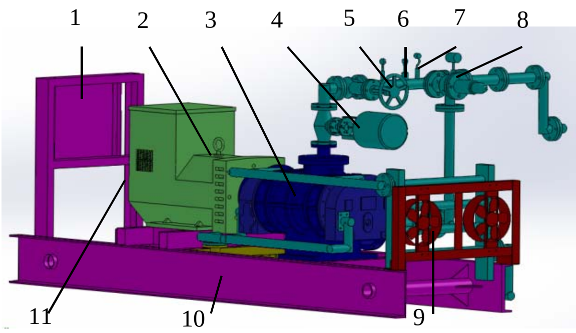


Fig. 2. The Roots-steam generator model.

Fig. 3. The photo of Roots-steam generator.

3.1. No Load-low Pressure Test

In this experiment, the electric control valve is fully open, without any adjustment. Firstly, for the sake of safety, the manual valve is opened a small angle (about 1/5). Observing the working state of the equipment, record the speed of the generator, the line voltage of AB, BC, and CA, the values of steam flow and steam pressure.

Secondly, increases the opening of the manual valve gradually, and record the relevant data. In this process, the generator vibration and accompanied by a sharp roar when the manual valve is in a small opening. Then the vibration decreases and the roar reduce, while the valve opening increases gradually.

Thirdly, when the valve opens to its 1/2, the voltage reaches the rated value. After that, the manual valve continues to open until it is fully opened, but the voltage is kept constant. The experimental data are shown in Table 1.

Table 1 shows when the steam pressure is increased from 0.03 MPa to 0.32 MPa, the steam flow from 0.13 t/h to 0.23 t/h, the generator speed increased largely, but little change in the output voltage;

When the speed is increased from 732 r/min to 986 r/min, the output voltage changes dramatically, and the pressure reaches 0.32 MPa, flow reaches 0.25 t/h;

Table 1. Roots - steam generator no load-low pressure related data.

Generator speed (r/min)	Line voltage of AB (V)	BC (V)	CA (V)	Steam flow (t/h)	Steam pressure (MPa)
210	10	3	7	0.13	0.07
265	32	40	38	0.19	0.09
732	46	42	49	0.23	0.25
986	138	143	150	0.25	0.32
1200	202	200	200	0.28	0.45
1270	290	289	284	0.37	0.59
1400	343	349	336	0.42	0.67
1430	363	369	355	0.45	0.68
1490	378	380	379	0.46	0.69
1700	383	385	383	0.48	0.77
1930	389	389	389	0.51	0.81

When the speed is increased from 1200 r/min to 1270 r/min, the average value of voltage increases by 87 V, flow rate, pressure increased respectively by 0.19 t/h, 0.24 MPa.

When the voltage reaches the rated value of the process, the rotational speed of the generator, the steam flow and the pressure change a little compared to the previous stage.

When the generator speed exceeds 1490 r/min, generator output voltage value remains unchanged.

In order to reflect the relationships between the voltage generated by the generator and the speed of the generator, the steam flow, the steam pressure more intuitively, Matlab is used to deal with the data in Table 1 in the Fig. 4, they are voltage - generator speed and voltage-steam flow-steam pressure (view from up to down) [17]. As it shown in Fig. 4, the output voltage and the steam flow, pressure, speed, like "S" –shaped curve.

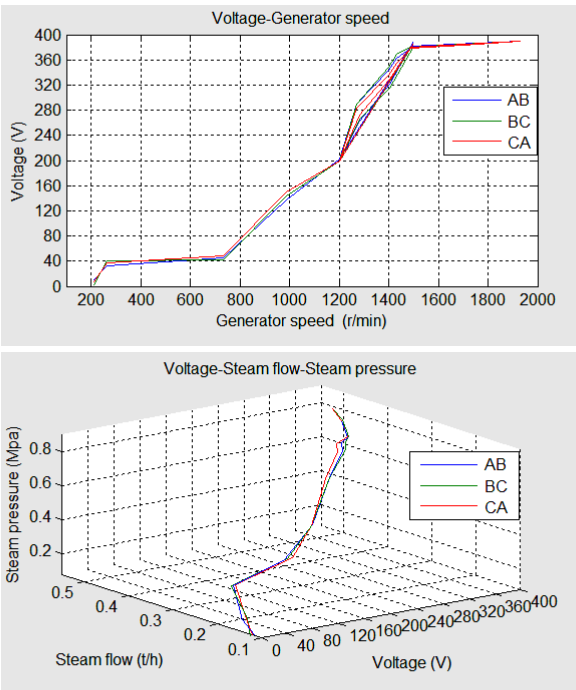


Fig. 4. Roots-steam generator no-load data curve.

Because of the limits of the generator, the output voltage isn't increase with the increase of the speed after the voltage reaches its rated value, this shown in the Fig. 4 (voltage - generator speed). The Fig. 4 (voltage-steam flow-steam pressure) show that the output voltage will not continue to increase with the steam flow and steam pressure when reaches the rated. And it also shows the relationships between voltage, steam flow and steam pressure. It can be see that the steam flow and steam pressure have great impact on the output voltage, but now there is no idea for how does it work. In the follow-up study will continue to explore.

3.2. With Load-low Pressure Test

To study the function of Roots-steam generator, a load of 35 kW was added to the original experiment. And as the same as the original experiment, the electric control vale doesn't work. Adjust the opening degree of the manual vale, observing and recording all data needed in this process, as it shown in Table 2.

Manual valve adjusted so that the generator output average voltage is 380 V, then 35 kW load connected, at the same time, the speed of generator immediately dropped to 1200 r/min, the output average voltage drops to 200 V. It can be found that the load have a significant impact on the Roots – steam generator.

Table 2. Roots-steam generator with load test data.

Generator speed (r/min)	Line voltage of AB (V)	BC (V)	CA (V)	Steam flow (t/h)	Steam pressure (MPa)	Load (kW)
1487	382	379	380	0.46	0.68	No
1200	202	200	200	0.44	0.74	35
1283	263	266	273	0.47	0.74	35
1403	321	315	329	0.49	0.78	35
1500	382	389	386	0.57	0.81	35

Studying the data in Table 2, steam flow and pressure increases, speed of generator increased to the rated speed gradually, the output voltage is also increased to the rated voltage, while the manual valve is opening gradually. Compared with no load, the steam flow increased by 23 %, the pressure increases by 19 %, the flow and pressure are two parameters has a direct bearing on the working efficiency of the generator.

3.3. Steam and Load Balancing Test

The above two groups of test were based on control of single variable, in order to study the ability of the generator system to adapt to the fluctuation of steam and the change of the load, the following experiments were arranged:

In fact that the steam used by generator system is in low quality – the steam flow fluctuations, the pressure changes. A set of automatic control system designed to study the generator system with the ability to adapt to harsh environment [18]. To form a closed control system, using Siemens PLC as the core controller, encoder as the feedback signal to collect the speed signal of generator at a certainty time. With the PID algorithm [19-21], the electric proportional control valve was controlled to keep the output voltage stable. The automatic control principle was shown in Fig. 5.

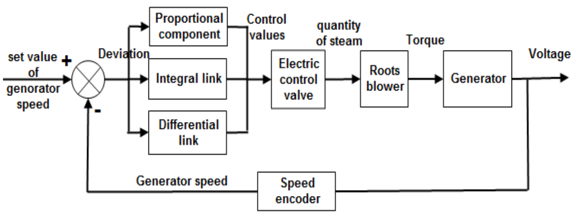
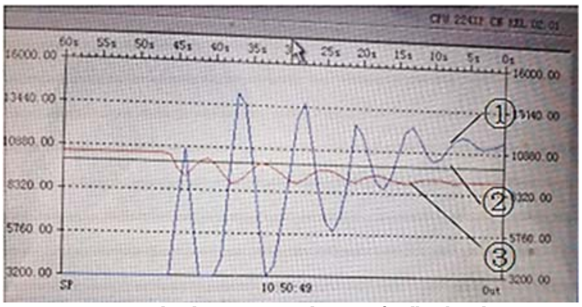


Fig. 5. Automatic control principle diagram of the generator.

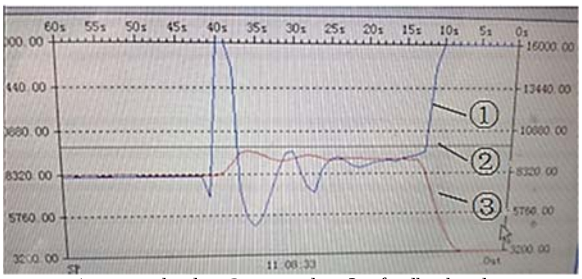
3.3.1. Regulation Test of the Fluctuation Steam

Connect 35 Kw load then make the manual vale fully open, then gradually decrease the valve opening and the increase the vale opening, repeat these several times. The adjustment process of PID was shown in Fig. 6. Then make the manual vale fully open, and regulate the vale arbitrarily until it fully closed. The adjustment process of PID became very violent, shown in Fig. 7.



1 – control value, 2 – set value, 3 – feedback value

Fig. 6. The regulating graph of increasing the valve opening.



1 – control value, 2 – set value, 3 – feedback value

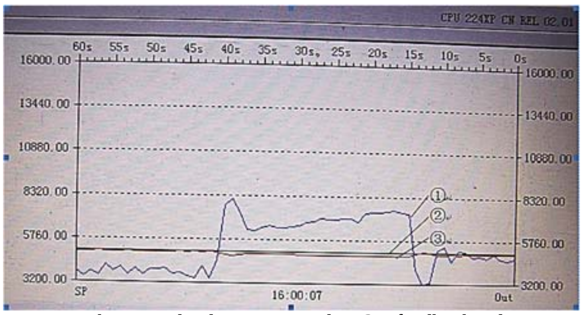
Fig. 7. The regulating graph of decreasing the valve opening.

Fig. 6 and Fig. 7 show that the generator system has obvious regulating effect on low quality steam.

3.3.2. The Regulation Test of Change Load

Regulation in a volatile source of steam prove that the generator system has obvious effect, so whether the load on the variations has the same effect? For this, load of 15 Kw will be connected to the system while the generator works normally with the load of 35 Kw. Due to the sudden increase of load impact on the system; the adjustment of electric proportional control valve becomes violent. The system will take some time to restore the balance, the adjustment time is shorter the system response fast, on the contrary it indicates poor adjustment. This process is shown in the Fig. 8.

When the load is suddenly disconnected will also impact on the whole system, the regulating effect diagram as shown in Fig. 8.



1 – the control value, 2 – set value, 3 – feedback value

Fig. 8. The regulation effect chart of changes load.

It can be seen from the Fig. 8, abrupt loading system requires adjustment time is about 5 s, and suddenly unloaded adjustment time is about 4 s, the adjustment of load weren't as good as the adjustment of fluctuation in steam.

4. Conclusion

By optimizing the design of the blades and internal rotor of the Roots blower, the lubrication system and cooling system were improved to enhance the sealing performance, reduce loss of steam energy and improve the power generation efficiency. The conclusions are as follows.

In the first experiment: the roots-steam generator can use the steam that pressure is less than 0.3 MPa, flow less than 0.15 t/h to generate electricity; when the steam pressure reaches to 0.69 MPa, the steam flow reaches to 0.46 t/h, the generator can produce the rated voltage of 380 V; it can inferred that the Roots-steam generator using low pressure saturated steam generation technology scheme is feasible.

In the second experiment: steam pressure is 0.81 MPa, flow is 0.57 t/h in the case the generator can generate electric power to drive the load 35 kW; the Roots-steam generator has capable of recovering waste heat and using low-pressure saturated steam to generate electricity.

In the third experiment: Roots-steam generator has a certain ability to adapt to steam of pressure greater than 0.45 MPa, flow greater than 0.28 t/h.

In the fourth experiment: Roots-steam generator 45 Kw and below the load on the third set of test conditions within a certain ability to adapt.

Through the above 4 groups of experiment can prove, reverse blower for power machine and using low-pressure saturated steam generation technology is feasible.

Although tests have shown that the Roots blower for steam generators has obvious ability to adapt for low-quality steam, there are still many areas can be optimized and improve. For example, using a faster response electric control valve, optimize the PID algorithm, use two leaves Roots blower or clover leaf twisting Roots blowers for power machine and so on. All above may cause different effects on the system. Need to study the relationship of the steam pressure and flow and Roots-steam generator work efficiency, the constraints of the pipe diameter and steam. It is also found that the air outlet of Roots blower has influence on the efficiency of power generation, but how does it work have not been found. In the following research, will continue to study the above problems and optimize the generator system.

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