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RETROFIT STUDY OF COMPRESSED AIR SYSTEMS IN NSRRC

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Abstract

This work aims to measure the energy consumption performance of compressed air systems, determine the weak points, implement economic assessments, and execute energy saving improvements in NSRRC. First, we regulated the compressed air discharge pressure at 6.0±0.5 kg/cm^2. Those compressors' specific energy requirements (SERs) are 7.74 ~ 20.05 kW/m^3/min. Then, we must repair or replace the inefficient compressors based on the performance results. Next, we decided on three phases implements: stop leakage in phase I, replace a compressor with VFD and a heat-regeneration desiccant drier in phase II, and connect TLS and TPS compressed air pipelines in phase III. Finally, we got significant energy savings of 543,754 kWh/yr and 4.3 years of pay-back time in capital investment.

INTRODUCTION

NSRRC currently operates two accelerators, the Taiwan Light Source (TLS) and the Taiwan Photon Source (TPS). The TLS, with a beam energy of 1.5 GeV and a circumference of 120 meters, was opened to users in 1993. The TPS, circumference of 518.4 meters, began its operation in 2015, equipped with a low-emittance synchrotron storage ring and booster synchrotron, producing a beam of energy of 3 GeV, shown in Figure 1.

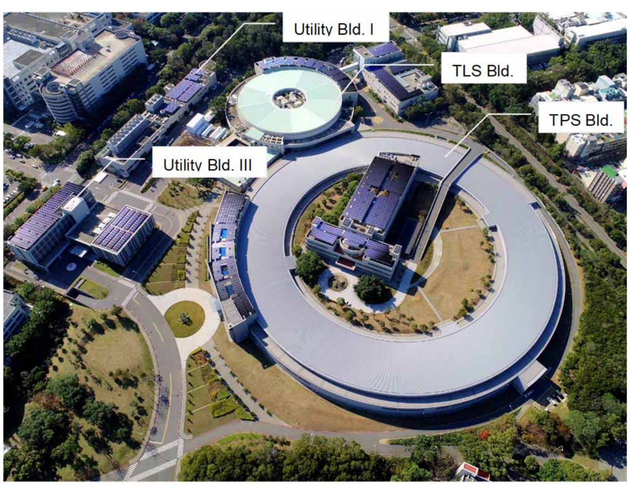

Figure 1: The TLS, TPS, Utility Bldg. I and III at NSRRC campus.

The TLS and TPS original compressed air systems scheme consists of six air compressors located in Utility Buildings I and III. Major uses of compressed air include the accelerator operations of pneumatic control valves and experimental instruments. That compressed air delivers through stainless steel main pipeline and polyurethane tube for users.

Four air compressors in Utility Buildings I for TLS are shown in Figure 2. Number 1 and 2 are oil-less lubricated screw compressors with 30 kW drive motors rated power and 3.6 m^3/min rated flow rate, utilized since 1992. Number 3 is also an oil-less lubricated screw compressor with 45 kW drive motor rated power and 7.2 m^3/min rated flow rate, utilized since 1990. Number 4 is an oil-free screw compressor with 37 kW drive motor rated power and 6 m^3/min rated flow rate, utilized since 2010. The rated discharge pressure of all TLS air compressors is 7 kg/cm^2. The maximum required pressure is 5.2 kg/cm^2, so we regulate the discharge pressure at 6.0 ± 0.5 kg/cm^2. Instantaneously maximum compressed air quantity of TLS is about 6.5 m^3/min; thus, we must operate two air compressors to achieve the flow rate. The TPS compressed air system scheme is similar to TLS, there are two 75 kW rated power oil-free screw compressors with variable frequency drive (VFD) motors and 13 m^3/min rated flow rate, utilized since 2014.

We must remove solid particles, water, and oil vapor from compressed air. According to the ISO 8573-1 standard, Class 1 in solid particles achieved by 0.1 µm and 0.01 µm micro-filter, Class 2 in water content (dew point equal to -40°C) achieved by refrigeration driers and desiccant driers, and Class 2 in oil vapor (0.1 mg/m^3) achieved by oil separators active carbon filters in TLS and Class 1 (0.01 mg/m^3) in TPS by oil-free air compressors.

The TLS air compressors control model of numbers 1 to 3 is conventional load / idle control, and number 4 is variable speed control. Therefore, we define the number 1 and 2 compressors as group 1 and the other two as group 2 and group 3, respectively. Each group runs for one week; the other groups are used as backups.

OPTIMIZATION POTENTIALS

Before we execute the optimization in energy saving of the TLS compressed air system, we have to check the set point of discharge pressure. By investigating points of use (POUs), we found required pressure is 5.5 kg/cm^2 for most users. However, the compressed air main pipeline is circular, and the pressure drops between the outlet of air compressors and POUs are always less than 0.2 kg/cm^2. Thus, we keep the discharge pressure at 5.7 ± 0.3 kg/cm^2.

The ideal temperature of the air compressor inlet is to retain 20°C~30°C -the TLS air compressors located in utility building I, where the temperature of air intakes is 26 ± 1°C. Therefore, we do not need to improve the temperature of the air compressor inlet.

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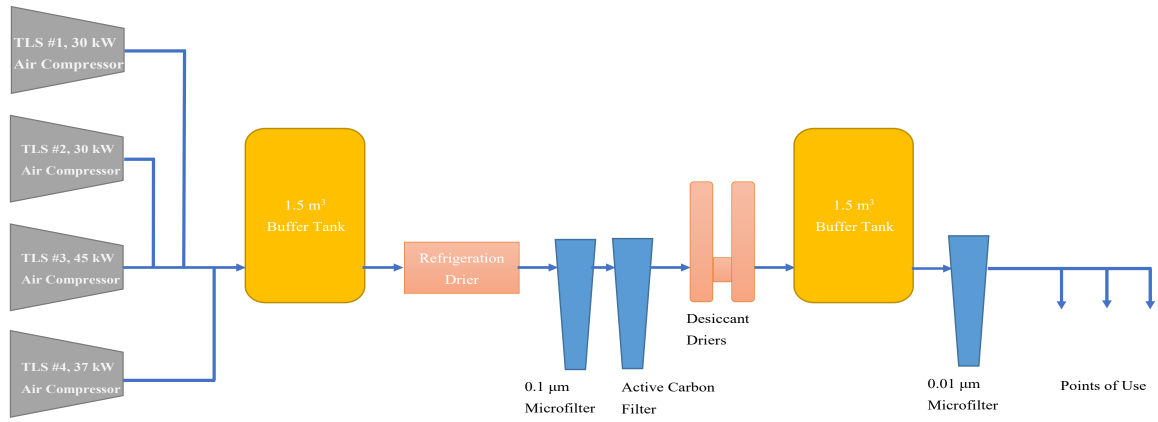

Figure 2: The scheme of TLS compressed air system.

We have scheduled a test of air compressors at 7.0 ± 0.15 kg/cm^2 in TLS and TPS, shown in Table 1. All of those compressors are water-cooled. We can discover that efficiencies of oil-free type compressors (item 4) drop sharply after running for 12 years. The specific energy requirements (SERs) are much higher than ISO 1217 Class 3 criteria (8.3 kW/m^3/min, when rated power ≤ 45 kW). However, the SER values of most oil-less type compressors meet the Class 3 energy efficiency benchmark. Based on the above results, we must decide whether to repair or replace the inefficient compressors.

During the TLS and TPS long shutdown period, we once conducted a leak test of the TLS compressed air system. In that period, both accelerators stopped running, and nobody entered the NSRRC site, but there was still a 6.3 m^3/min compressed air flow rate observed by TLS air compressors. Therefore, deducting cryogenic equipment's required air flow rate, 1.8 m^3/min of air leaked. Using ultrasound detection technology is an opportunity to stop leakage for energy saving [1].

The desiccant drier installed in TLS compressed air system is a heatless, which consumes more than 15% well-treated air for regeneration. So that is a chance we can replace heatless desiccant by heat regeneration once for energy saving. Furthermore, zero air condensate drains could reduce compressed air leakage [2].

Table 1: Air Compressors Performance Test Results in TLS and TPS

Item	Name	Compressor type	Rated power (kW)	Actual power (kW), A	Rated flow rate (m^3 min^{-1})	Actual flow rate (m^3 min^{-1}), B	SER (kW m^{-3} min), A/B
1	TLS #1	Oil-less screw	30	25.2	3.6	3.22	7.83
2	TLS #2	Oil-less screw	30	26.1	3.6	3.37	7.74
3	TLS #3	Oil-less screw	45	48.6^b	7.2	6.08	7.99
4	TLS #4	Oil-free screw	37	41.7^b	6	2.08	20.05
5	TPS #1	Oil-free screw ^{a}	75	95.6^b	13	9.20	10.39
6	TPS #2	Oil-free screw ^{a}	75	95.0^b	13	10.06	9.44

$^{a.}$ Compressor with VFD.
$^{b.}$ Service factor = 1.3.

RESULT AND DISCUSSION

Following the assessment, our implementation strategy was divided into three phases and focused on repairing system leaks, replacing the poor efficient air compressors, condensate drains, and heatless-regeneration desiccant drier. Then, we must optimize the control model, keeping old oil-less air compressors as a full load. Finally, the insufficient airflow is compensated by a new compressor with a variable frequency drive (VFD). Ultimately, conducting the pipelines of TLS and TPS were applied to raise the reliability and flexibility simultaneously by dispatching compressors. We describe the details of the three phases implements.

Phase I

When we improve the air leak, the compressed air saving is about 1.8 m^3/min (cubic meter per minute, CMM). Then we can calculate the sum of annual energy saving both in a new compressor with VFD (SER = 5.8 kW / CMM) and an existing 30 kW compressor with loaded/unloaded model was 103,580 kWh/yr.

The two operation models are below:

Model 1. The new compressor with VFD will be installed in TLS and run for 6,720 h/yr (80% of 8,400 h).

Model 2. An existing 30 kW compressor consumes 25.7 kW on average at loaded status and 12.8 kW at unloaded status. Therefore, the ratio of these two statuses is estimated 56% and 44% for supplementing 1.8 CMM leaked air for 1,680 h/yr (20% of 8,400 h).

The Power price is 3.38 NTD / kWh, equal to 0.096 Euro/kWh. Annual power cost saving was 9,943 Euro/yr. The capital investment of the ultrasonic leakage detector is 6,700 Euro. Therefore, the payback period is determined as 0.67 years.

Phase II

The target we want to renew is TLS 37-kW oil-free compressor, whose SER value reaches 14.95 kW/CMM. If we spend 17,000 euros to repair the shaft seal to overcome

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the inefficiency, the validity period is only 8~10 years. Considering the maintenance cost in 20 years, we plan to replace this oil-free compressor with an oil-less one with VFD and a 6-pole IE4 grade motor. A lower speed of 1,200 rpm helps extend the life of compressors. A new oil-less compressor with VFD and 6-pole IE4 motor, a heat-regeneration desiccant drier, and 10 zero air condensate drains cost 66,000, 55,000, and 2,000 Euro, respectively.

Variable speed operation of the new compressor with VFD was the primary model, supplemented by the three existing fixed-frequency compressors in demand pressure control. These two operating models were approximately 80% and 20%. The cost of the control panel modified is 40,000 Euro.

Before replacing the compressor with VFD and heat-regeneration desiccant drier, the average annual energy consumption of the existing four compressors was 438,617 kWh/yr, and the annual power cost of the existing four compressors was 42,107 Euro/yr.

Factor 1.15 is the loss of heatless-regeneration desiccant driers and conventional condensate drains. The three operation models are below:

Model 1. One existing 30 kW compressor consumes 25.7 kW at the loaded status, and 12.8 kW at unloaded status; another existing 37 kW compressor consumes 41.7 kW at loaded status and 20.8 kW at unloaded status. Therefore, the ratio of these two statuses is estimated at 96% and 4% for discharging 4.5 × 1.15 CMM compressed air for 2,800 h/yr.

Model 2. Two existing 30 kW compressors consume 51.3 kW at loaded status and 25.7 kW at loaded status. The ratio of these two statuses is 78% and 22% for discharging 4.5 × 1.15 CMM compressed air for 2,800 h/yr.

Model 3. An existing 45 kW compressor consumes 48.6 kW at the loaded status and 24.3 kW at the loaded status. Therefore, the ratio of these two statuses is estimated at 85% and 15% for discharging 4.5 × 1.15 CMM compressed air for 2,800 h/yr.

After replacing the compressor with VFD and heat-regeneration desiccant drier, compressors' average annual energy consumption was 247,873 kWh/yr. The two operation models are below:

Model 1. The new compressor with VFD will be installed in TLS and run for 6,720 h/yr (80% of 8,400 h).

Model 2. Two existing 30 kW compressors consume 25.7 kW at loaded status and 12.8 kW at unloaded status. Therefore, the ratio of these two statuses is estimated at 68% and 32% for discharging 4.5 CMM compressed air for 1,680 h/yr.

The annual energy saving is 190,744 kWh/yr, and the annual power cost saving is 18,311 Euro/yr.

The capital investment for a new compressor, control panels, desiccant driers, and condensate drains are 66,000, 40,000, 55,000 and 2,000 Euro. Therefore, the payback period is determined as 8.9 years.

Phase III

When we complete the connection of the TLS and TPS compressed air pipeline, the total compressed air requirement in NSRRC is about 10.7 m^3/min. Therefore, we will eliminate the two oil-free compressors with VFDs of TPS since the bed SER values are 10.39 kW /CMM and 9.44 kW /CMM.

The annual energy consumption of TPS compressors with VFDs was 594,300 kWh/yr, and annual power cost was 57,053 Euro/yr.

After the connection of TLS and TPS compressed air pipeline, the annual energy consumption of compressors could be calculated was 344,870 kWh/yr.

The two operation models are below:

Model 1. The new compressor with VFD will be installed in TLS and run for 6,720 h/yr.

Model 2. Two existing 30 kW and 45 kW compressors consume 25.7 kW and 48.6 kW at loaded status, 12.8 kW and 24.3 kW at unloaded status. The ratio of these two statuses is estimated at 65% and 35% for discharging 6.2 CMM compressed air for 1,680 h/yr.

The annual energy saving is 249,430 kWh/yr, and the annual power cost saving is 23,945 Euro/yr. The capital investment for pipeline connection and oil catalytic converter are 10,000 and 45,000 Euro. Therefore, the payback period is 2.30 years.

Coupling the pipelines in TLS and TPS junction place was employed, and installed a buffer tank there to connect both TPS 4-inch main pipe and TLS 3-inch main pipe and minimize pressure pulse simultaneously. These 6 air compressors were the same group when we finished this work. Furthermore, we installed an oil catalytic converter for oil vapor archiving ISO 8573-1 Class 1 (0.01 mg/m^3) in TLS compressed air system. The capital investment of phases I~III and energy conservation summarized in Table 2.

Table 2: Summary of Energy Savings of Efficiency Improvements

Phase	Action	Energy Saving	Power Cost Saving	Capital Investmen t	Paybac k Period
		(kWh/yr)	(Euro/yr)	(Euro)	(yr)
I	Stop leak	103,580	9,943	6,700	0.67
II	Replace equipment	190,744	18,311	163,000	8.90
III	Connect pipeline	249,430	23,945	55,000	2.30
Sum		543,754	52,199	224,700	4.30

CONCLUSION

The power consumption is about 70 GWh/yr in NSRRC. Retrofit of compressed air systems both in TLS and TPS gained about 0.543 GWh/yr, equal to reducing 276.8 tons of CO_2 emission. Although the capital investment costs 224,700 Euro, the payback time is just 4.3 years.

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