When Your High Speed Turbine Blows…UP!

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ABSTRACT

Energy saving turbine blowers have been installed in numerous municipal and industrial wastewater treatment facilities throughout the last ten years. Engineers and operators are adjusting practices to the nuances introduced with this new style of blower, including learning some hard lessons during the start-up process. Recent case studies of these installations have yielded data regarding critical design and commissioning elements. Key conclusions of these studies are:

1. The standard blower manifold arrangement (single blow-off valve, discharge check valve, silencer) is vital to success and should not be modified.

2. Control strategies that make full use of the advanced features of the turbine blower (precise control, logic controllers for high efficiency operation, etc.) and minimize complex interactions with older blowers are more successful.

3. Performance testing of complete units should be done in the factory and the field to demonstrate compliance with specified energy guarantees and performance requirements.

KEYWORDS: Turbine blower, energy, aeration, secondary treatment, start-up.

INTRODUCTION

Over the past 5-10 years, high speed turbine blowers have quickly moved from an industry unknown to the preferred design alternative at wastewater treatment plants. The energy efficient design, taking advantage of frictionless (air/magnetic) bearings, provides an effective means to reduce electricity consumption at one of the most significant points in any secondary treatment system, the aeration blowers. Municipalities around the country are taking advantage of the energy savings, as well as available funding grants from local energy providers, to swap out their older centrifugal and positive displacement blowers with new high speed turbine units. Engineers and operators have had to adjust to the nuances introduced with this new style of blower, including learning some hard lessons during the start-up and commissioning process.

The learning curve is further complicated by new manufacturers entering the turbine blower market in rapid succession to meet the demand for more energy efficient operation of secondary treatment systems. Each new manufacturer, while using many of the same core principles of turbine blower design, provides a unique machine with subtle differences that can turn into unexpected surprises when plant staff first hit the "go" button.

THE PROBLEM

Incorporating high speed turbine blowers into an existing aeration system is not as simple as removing old units and installing new turbine blowers in a "plug and play fashion," as many of the manufacturers are promoting. Design and operation must consider a variety of factors that can lead to inefficient operation and failure if not addressed:

- The turbine blowers employ variable frequency drive (VFD) technology and the resultant effects of the electrical harmonics produced by VFD's on the facility's electrical distribution system must be evaluated and resolved.
- Incorporating the new blowers into the control system of the existing facility can be problematic, as inlet control valves on the old standby multistage centrifugal blowers react differently than the VFD's on high speed turbine blowers.
- Piping configurations within and external to the blower room must be carefully considered as the high speed turbine units MUST startup under no backpressure load.
- Determining a consistent, accurate methodology to assess start-up conditions and specify required power savings is essential to both compare blowers from different manufacturers as well as field test whether or not a specific unit is meeting the specified energy demand.

APPROACH

Analysis of these key design and operational factors was conducted by reviewing several recent turbine blower installations. Each case study presented an opportunity to evaluate one or more of the factors in action and determine its effect on the overall quality of operation. By collecting data from a variety of installations common approaches to operation can be vetted under multiple circumstances, allowing improper design assumptions to be identified. The following section provides a discussion of each case study, followed by concluding recommendations for both design engineers and operations staff.

DISCUSSION

Three recent start-up case studies presented an opportunity to address solutions to common challenges during turbine blower start-up and commissioning.

Case Study #1: Blow-off Valve Configuration and Performance Tuning

A 400 hp turbine blower was installed to replace a series of existing 500 hp single stage centrifugal blowers utilized for secondary aeration (and nutrient removal) at a mid-size wastewater plant (average flows of 11-15 million gallons per day (MGD)). The turbine blower (Figure 1) was a relatively unique design that combined two cores into a single enclosure with one HMI (human-machine interface). Typically, each core is located in its own enclosure as a completely separate unit, and placed in parallel with additional blowers. In this case, a single blower controlled two cores simultaneously. The discharge manifold was a custom, twin outlet design, built so that the new blower could slip into the existing footprint of one of the older blowers and connect to the existing discharge and suction piping with minimal modifications. This was intended to save construction and design cost, maximizing the long-term payback of the project and providing justification for grant funding from the local utility board.

The blower was originally procured through a competitive proposal process, which included both capital cost as well as guaranteed power consumption requirements at a specified range of flow and pressure values. Field testing of these power requirements would be a necessary part of post start-up data collection in order to validate the grant funding. Table 1 provides an example of the information that was provided from the successful bidder as a means to compare potential vendors as well as evaluate the performance of the purchased unit once installation was complete. The key part of the table is the guaranteed wire-to-air power value, which each proposed vendor was required to submit at the design conditions specified. This would provide the key comparative variable to ensure that field performance matched contract requirements.

Figure 1. Twin core and dual outlet manifold turbine blower installation. Note the dual silencers projecting up from the discharge manifold.

Table 1. Power guarantee for blower procurement and evaluation. The wire powers listed are the values provided by the manufacturer.

Design Point	Capacity, %	Flow, m^3/min (SCFM)	Pressure, kPa (psia)		Inlet Temp, DegC (F)	Rel Hum, %	Guaranteed Wire Power for system, KW
			Baro	Outlet			
1	100	170 (6,000)	101 (14.7)	184 (26.7)	20 (68)	36	282.6
2	80	140 (4,800)	101 (14.7)	184 (26.7)	20 (68)	36	218.4
3	40	70 (2,400)	101 (14.7)	184 (26.7)	20 (68)	36	109.2
4	25	43 (1,500)	101 (14.7)	184 (26.7)	20 (68)	36	70.6

*Wire KW consists of Blower, Motor, VFD or inverter, and any cooling or other auxiliary systems if used.

The following three challenges were encountered during start-up testing:

Challenge #1 - Meeting Energy Requirements in the Field: Tuning the machine to achieve energy guarantees in the field, as well as meet the minimum and maximum flows, required very precise adjustments and was subject to atmospheric field conditions.

Table 2 provides a summary of the factory tested wire-to-air power for the selected blower. The installed blower used two cores to achieve the specified flow range, thus, the factory testing was done on each blower core individually up to 85 m^3/min (3,000 standard cubic feet per minute (SCFM)) to achieve the total requirement of 170 m^3/min (6,000 SCFM). The wire-to-air power achieved was consistent with the guaranteed results and the blower was approved for field installation.

Table 2. Factory results for comparison with procurement power guarantee (Table 1).

Design Point	Capacity, %	Flow, m^3/min (SCFM)	Pressure, kPa (psia)		Inlet Temp, DegC (F)	Rel Hum, %	Factory Wire Power for system, KW
			Baro	Outlet			
1	50	85 (3,004)	101 (14.7)	185 (26.8)	20 (68)	36	138.1
3	40	68 (2,407)	101 (14.7)	185 (26.8)	20 (68)	36	106.8
4	25	43 (1,509)	101 (14.7)	185 (26.8)	20 (68)	36	68.8

*Wire KW consists of Blower, Motor, VFD or inverter, and any cooling or other auxiliary systems if used.

Though it may seem intuitive, field personnel must be cognizant of the fact that specifications and “guarantees” are typically written in the language of standard temperature and pressure (STP) or normal temperature and pressure (NTP). While this is necessary to provide a baseline over which all units can be compared, especially for bidding purposes, the odds that start-up conditions will match STP is virtually zero. Thus, field testing must normally be translated from one thermodynamic condition (field conditions) to another (STP) in order to validate that a unit is operating properly. This is a calculation that any vendor can do with the appropriate knowledge of the blower internal efficiencies and standard thermodynamic equations. If testing is conducted during warmer weather, compression of the air requires greater energy input (and thus less efficient blower operation) than what would be expected at STP.

In addition, this particular blower was required to achieve a 4:1 turndown under STP conditions, operating from 43 m^3/min (1,500 SCFM) to 170 m^3/min (6,000 SCFM). However, as with energy efficiency, the ability to hit low and high flow conditions will be somewhat dependant on atmospheric conditions during testing. The actual low point in the field during these tests, for example, was higher than expected due to the warmer inlet air. In order to achieve 43 m^3/min (1,500 SCFM) adjustments were made to the internal programming to allow operation near the surge line. Consequently, the blower operated at the widest range possible. This required careful review of all the available data that a turbine blower HMI can provide (Figure 2 provides an example of typical output data common to many blower manufacturers). Operational modifications often required programming adjustments that can only be performed by the manufacturer to ensure safe operation of the unit.

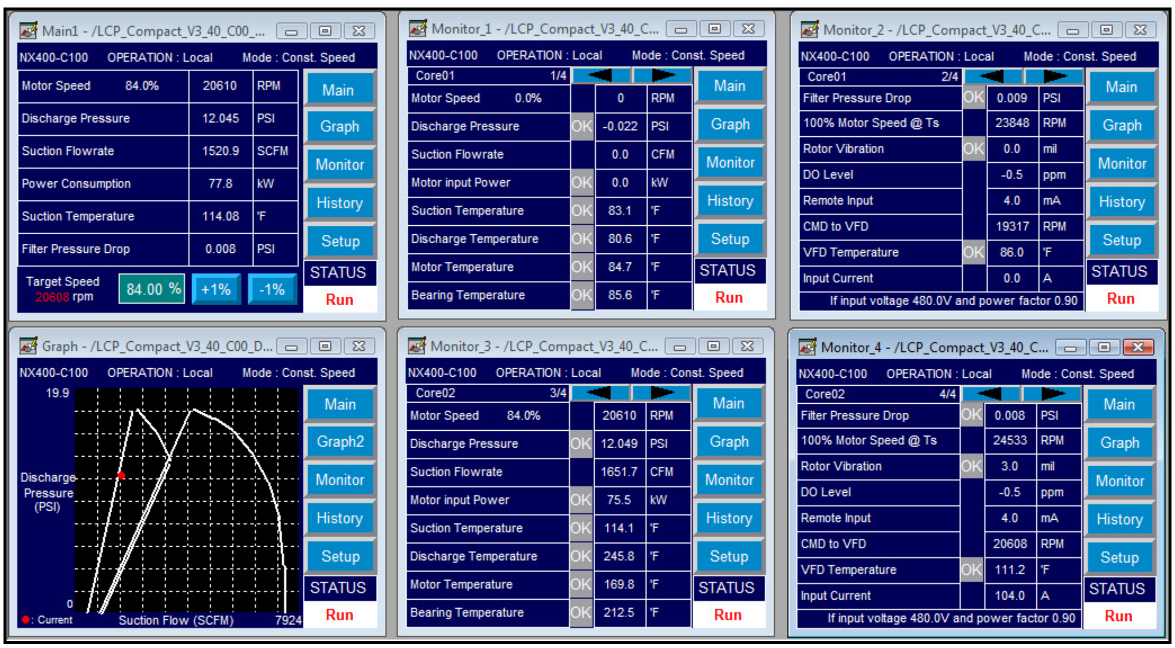

Figure 2. Example HMI output for field analysis and tuning of a typical turbine blower. (Courtesy of APG-Neuros).

Table 3 provides a summary of the field testing results in comparison with the factory testing results. Note that the wire-to-air power is higher than expected at the given flows due to the field conditions encountered. Consequently, the factory test results are adjusted (via calculation) to account for the alternate temperature, pressure, and humidity and provide for a direct comparison translated from STP conditions. With the exception of two moderate differences at design points

#1 and #3 (shown in red), the unit appeared to perform adequately in the field and meet the expected overall power efficiency.

Table 3. Field test results for comparison with factory test results (Table 2). The wire powers highlighted in red indicate field power requirements greater than the factory test results.

Design Point	Capacity, %	Flow, m^3/min (SCFM)	Pressure, kPa (psia)		Inlet Temp, DegC (F)	Rel Hum, %	Wire Power for system, KW
			Baro	Outlet			Field/Factory
1	100	172 (6,073)	101 (14.6)	184 (26.7)	37 (98.7)	44	329/327
2	80	137 (4,827)	101 (14.6)	183 (26.6)	39 (102.3)	51	236/244
3	40	69 (2,424)	101 (14.7)	184 (26.7)	42 (108.3)	55	132/125
4	25	43 (1,507)	101 (14.7)	185 (26.8)	49 (119.8)	60	82/82

*Wire KW consists of Blower, Motor, VFD or inverter, and any cooling or other auxiliary systems if used.

Challenge #2 - Harmonic Impacts on Electrical Performance: Use of appropriate harmonic mitigation equipment when installing a large VFD was essential to electrical performance and equipment protection.

Figure 3 provides an example of an electrical one-line diagram that emphasizes a key feature that should be included on any large (> 50 hp) turbine blower installation: a harmonic filter. As with any significant VFD installation, there is a risk that damaging harmonic effects may be transmitted from the VFD to the electrical bus, affecting neutral wires, voltage regulators, ballasts, instrumentation, and power supplies on equipment connected to the same system. This effect is a natural by-product of a VFD and requires some form of filter (active, passive, low pass, etc.) to mitigate the effects and protect the distribution system.

The fact that turbine blowers are often installed on existing electrical systems that may not have previously included a VFD makes a filter even more important. A common method of ensuring protection for retrofit installations is to require the blower manufacturer to comply with IEEE 519 (Institute of Electrical and Electronics Engineers: Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems). This usually means that the blower package will include a low pass harmonic filter (as seen in Figure 3) as an equipment specific means of filtering harmonic distortions. If the blower installation is a new one, the design engineer can include active or passive filters on the collective power system to achieve the same effect.

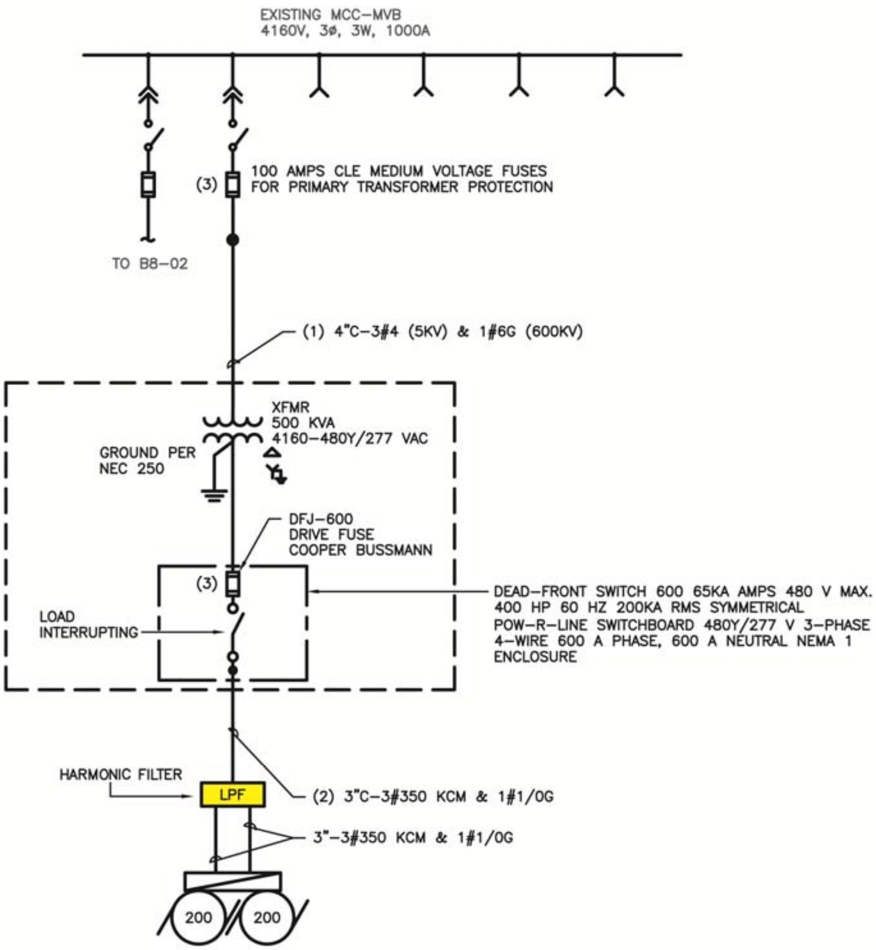

Figure 3. Example one-line diagram, including a low pass harmonic filter (LPF) to mitigate system harmonics from a dual core turbine blower.

Challenge #3 – Design of Blow-off Valve Manifold: Coordination of the twin blow-off valves (which were not factory tested and are usually not piped together, as in Figure 4) created an unexpected backflow pattern between cores (and consequently a core failure). The blow-off valves were re-piped to prevent a recurrence.

Currently, most turbine blower specifications require complete unit UL (Underwriter Laboratories) ratings as well as complete system testing per ASME (Performance and Test Code) PTC-10. Because this particular blower had a unique twin core design, the testing was not done as a complete unit, but each core was tested separately. Each core had its own blow-off valve. During design and field installation, in order to connect the piping manifold to the existing blow-off connection (Figure 4), the blow-off valves were tied together with an orifice place on the outlet of each unit. When field testing commenced a vibration problem was noted during certain instances when cores were transitioning between operational states. The orifice plate did not suffice to prevent outlet flow from an open blow-off valve bleeding back into the unit, resulting in a core seizure and ultimate failure. The blow-off valve outlets were re-piped to fully separated outlets (with individual silencers), removing the problem connection and solving the operational issue.

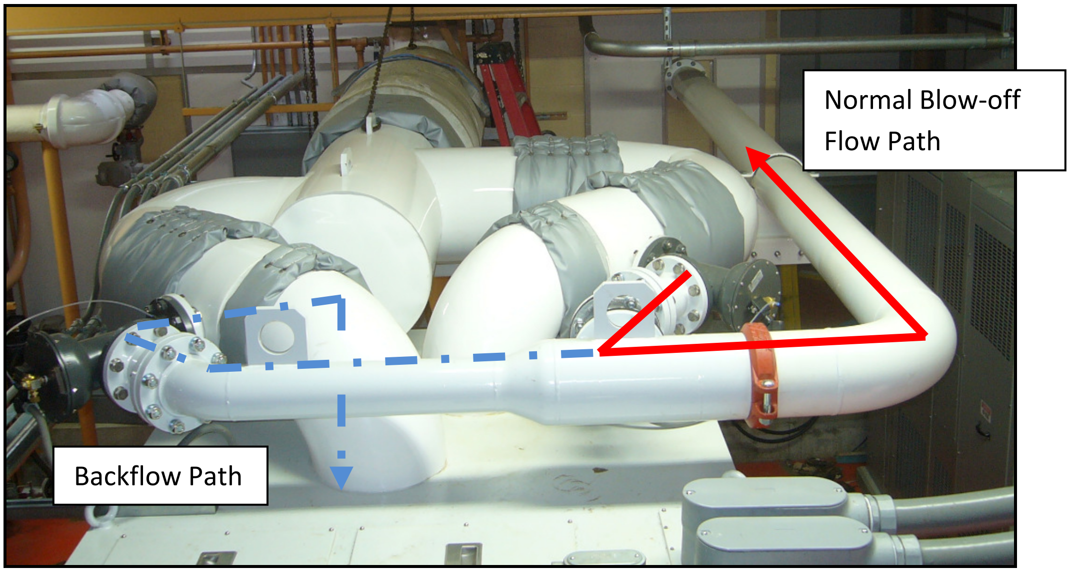

Figure 4. Original blow-off valve manifold that created a catastrophic core failure. The blue line indicates the bleed pathway that allowed air to bypass from one core to another.

The new blower is currently operating and functioning as intended, meeting the flow range and power consumptions requirements after the modifications previously listed were implemented and validated.

Case Study #2: No Blow-off Valve in Original Installation

Full operation of a blower that was intended to be a simple swap out for an older, existing blower was delayed several months due to an attempt to "simplify" the layout. The initial arrangement of the blower from the manufacturer did not utilize a blow-off valve (Figure 5), and thus required the blower to start-up against the full backpressure of the aeration basins. This led to vibration issues and immediate shutdown of the unit. The low friction bearing and core were unable to ramp up to a full, stable operating condition under the typical 3.0 - 4.6 m (10-15 ft) of static discharge head in the aeration basin. The system vibration caused obvious and severe shaking of the installation and lead to a six-week delay in commissioning. Design performance was only achieved after implementing a revised piping configuration and blow-off valve from the manufacturer, returning the unit to what is typical for nearly all installations: a discharge manifold with blow-off valve, silencer, and integral check valve.

Figure 5. Blower outlet piping without a standard blow-off valve to provide a low pressure start-up condition.

Case Study #3: Integration of Controls Combining Old and New Blower Systems

High speed turbine blowers (Figure 6) were installed for a new activated sludge system in an attempt to operate them in conjunction with the existing activated sludge system, which remained in service. The new blowers had their own internal control system for dissolved oxygen control, provided as part of the vendor supplied programmable logic controller (PLC). The old header pressure/inlet valve controls on the existing blowers caused sporadic control issues between the two blower systems. The issues centered on toggling the blowers ON and OFF when air demand changed.

Older blower systems with positive displacement or multi-stage centrifugal blowers often utilize turning vanes and throttling controls to modulate flow rates. When a VFD controlled turbine blower is introduced into the system, it is often tempting to maintain the distinct control systems of each blower and expect them to smoothly work together. The plant control system is intended to throttle the old blower while allowing the turbine blower to simply adjust outlet frequency to modulate speed. When this is combined with a “most-open-valve” control system for modulating flow into individual basins, the result can be a complex net of conflicting requirements, with two different blower types controlled in two different ways, attempting to control the same parameter (basin dissolved oxygen) with their own unique response times and control loops. The interaction problems between each blower resulted in repeated trips to the site by the blower manufacturer and the plant's control operator to eventually resolve the issue.

Figure 6. High speed turbine blowers installed for a new activated sludge system. The new blowers were combined with the existing blower control system after several integration challenges were overcome.

CONCLUSIONS

Design engineers should carefully consider the following issues when developing specifications and layout drawings for turbine blower installations:

- The standard blower manifold arrangement (single blow-off valve, discharge check valve, silencer) is tried and true. Be particularly cautious when modifying this design. The blower will work very well under the standard arrangement, which is the common type of arrangement tested in the factory. Engineers should design around that standard as much as possible.

- Utilize control strategies that make full use of the automatic features of the turbine blower and minimize complex interactions with existing, less sophisticated blowers. In the case of an older positive displacement or centrifugal blower, it may be advantageous to use the older blower to base load at a constant speed while leaving the turbine blower to modulate and control at a higher degree of precision. This will avoid conflicting control strategies that may lead to difficulty during start-up and normal operation.

- Utilize harmonic filters to protect the electrical distribution system, either through the design of filters on the primary electrical bus, or through low pass filters provided as part of the blower manufacturer's supply package.

Factory and field conditions must match to assure a successful installation. Engineers and Owners should require the following parameters to be demonstrated during factory testing as well as in the field under actual operating conditions:

- Assembled units need to be tested as they will be configured in the field, including "special" inlet or discharge configurations. Do not accept a unit delivered to the field that has not undergone full PTC-10 testing as a complete unit.

- Performance testing of assembled units should be done in the factory as well as in the field to demonstrate compliance with the contract requirements and guarantees. These guarantees must be clearly presented in the specifications (Table 1 as an example) and enforced. If conditions other than STP are required, the engineer should specify precisely what inlet conditions should be used for testing (temperature, pressure, humidity) and what conditions will be required as the normalized standard to which all field testing must be compared for compliance verification.

- The turbine blower installation will require fine tuning of the new energy efficient machines into the existing control system. If the existing control system involves complex features, including most-open-valve scenarios, the interaction of the blower with the plant control system will take time to precisely tune. This tuning will require control personnel from both the Owner and blower manufacturer to be involved in order to resolve problems and integrate the system quickly.

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Though we have kept the case study participants anonymous in this paper, the authors acknowledge and appreciate the vital assistance from the various wastewater plant staff and turbine blower manufacturers in working through the common challenges of commissioning. These issues are all the more important when new technologies enter the market, and the valuable lessens learned will promote better designs by engineers and better operation by plant staff.