Cost Effectively Increasing the Filtration Area in Fabric Filters for Large Power Plants

Peter Wieslander[1], Stephen L. Francis[2]
(1 Alstom Power Sweden AB, P.O. Box 1233, SE-351 12, Växjö, Sweden
Email: peter.wieslander@power.alstom.com
2 Stephen L. Francis, Alstom Power Inc. 1409 Centerpoint Blvd. Knoxville, TN 37932, USA.
E-mail: steve.l.francis@power.alstom.com)

Abstract: The market demand for very low outlet particulate emissions from power plants is resulting in the choice of fabric filters (FFs) over electrostatic precipitators (ESPs) in many projects. For the same flue gas volume flow, the higher the required removal efficiency, the choice between ESP or FF tends to favor the FF, due to its lower capital cost. As a result of the increasing demand for FFs, suppliers need to meet the market requirements by providing properly designed, efficient, cost effective FF designs. Many of the projects requesting FFs today are for coal fired boilers. As the size of the boiler increases, the larger the amount of flue gas that needs to be cleaned, and the larger the size of the FF. Increasing the filtration area in each compartment of a FF to meet this need is not a simple process of scale-up. Maintaining low outlet emissions, the same or lower FF pressure losses, and equal or longer bag life are all key factors. As the filtration area in each filter compartment increases, the amount of flue gas and dust entering the compartment increases, and the risk of performance, pressure drop and bag life problems increases if the compartment arrangement is not designed properly. Alstom Power Systems (APS) is currently completing an extensive effort of increasing the amount of filter area that can be installed in each compartment of a FF. This paper presents the key aspects of design to address gas and dust distribution, and pressure drop issues, as well as the pulse cleaning system design and capacity. APS is actively working in the research laboratory as well as in new FF installations to demonstrate the success of the new design.

Keywords: Fabric filter, power plant, dust emission, pressure drop, flow modelling, pulse cleaning

1 INTRODUCTION

High ratio fabric filters (HRFFs) are gaining market share over ESPs for power plant applications, for a number of reasons.

The HRFF design has proven its ability to achieve low dust emission in a wide variety of applications. Emission guarantees of 1-2 mg/Nm^3 have been given and achieved, and actual emission levels of 0.1–0.2 mg/Nm^3 have been demonstrated [1]. For power applications, the most stringent emission demands are today in the 5-10 mg/Nm^3 range, and emission demands of less than 20 mg/Nm^3 are regularly encountered. Such emission guarantees can be met in a cost effective manner with a well designed, properly sized HRFF. While ESPs can be sized to meet this level of outlet emissions, the size and cost of the ESP required would be unacceptably large.

A major advantage of a fabric filter is its ability to cope with virtually any fly ash, with practically no change in the outlet emission. This allows the user to burn a wider range of fuels than would be possible with an ESP. The particulate collection in a fabric filter is not effected by the electrical properties of the ash. The tolerance for variations in boiler operation is larger for a HRFF than with an ESP, provided the gas temperature entering the filter stays at or below the maximum design level.

In a HRFF, the ash-laden gas is filtrated through the bags. The ash is deposited on the surface of the bags, and the layer of ash becomes an integral part of the collection mechanism. The combination of a high efficiency filter material, and efficient filtration in the ash layer, enables efficient removal of a large portion of the finest particles, a feature that is becoming increasingly important as health concerns over sub-micron particle inhalation will impose more stringent control of fine particle emissions. Fine particles are enriched in harmful heavy metals such as e.g. As, Cd and Pb. A fabric filter efficiently collects the very finest particles, and may also be designed in such a way that a $PM_{2.5}$ emission goal can be obtained [2].

Another advantage of a HRFF is that for applications where absorption of acidic gas components (e.g. SO_x), or mercury, is needed, and a sorbent is injected upstream the filter for that purpose, further gas absorption takes place in the dust layer formed on the bags. The dust layer contains reactive absorbent materials, resulting in enhanced absorption efficiency of acid pollutants, as well as better utilization of the sorbent material. Fabric filters offer a distinct advantage for scrubbing with dry sorbents in its capability of further enhancing, as compared with ESPs, the absorption process, due to the forced contact with the absorbent on the surface of the bags. The fabric filter thus has the dual capacity of particulate control device and chemical reactor [2, 3].

HRFFs are normally compartmentalized, which allows for on-line maintenance of most components to accommodate emergency maintenance requirements, and gives high operating availability, very close to 100%. For a HRFF, maintenance work can be performed from the clean gas side under ambient conditions, which is an advantage with respect to the working conditions for the maintenance personnel.

APS has delivered in-house designed fabric filter systems for power plants on more than 20 000 MWe installed capacity world-wide. The first OPTIPULSE® HRFF utility plant was commissioned in 1978 at the coal-fired 60 MWe Kyndbyverket Power Station in Denmark. The OPTIPULSE® FF was the first pulse jet filter capable of cleaning filter bags longer than 4 m on-line. Since then, the boiler sizes, and bag length, have increased substantially. Presently, APS has successfully operating HRFFs on 750 MWe boilers, and an order has been received for an 850 MWe boiler, which will be commissioned in 2009. 8 m long bags, on-line cleaned, have been successfully used for more than 15 years in utility applications [4]. Several orders for power plants have now been received with 10 m long bags, and the first unit with 10 m long bags has recently been successfully commissioned.

As a result of the increasing demand for HRFFs, suppliers need to meet the market requirements by providing properly designed, efficient, cost effective HRFF designs. As the size of the boiler increases, the larger the amount of flue gas that needs to be cleaned, and the larger the size of the HRFF. Increasing the filtration area in each compartment of a HRFF to meet this need is not a simple process of scale-up. Maintaining low outlet emissions, the same or lower FF pressure losses, and equal or longer bag life are all key factors for the end user. As the filtration area in each filter compartment increases, the amount of flue gas and dust entering the compartment increases, resulting in increased risk of performance, pressure drop and bag life problems if the compartment arrangement is not designed properly.

APS is currently completing an extensive effort of increasing the amount of filter area that can be installed in each compartment of a HRFF.

The new FF design aims to reduce the capital cost - as well as offer a smaller footprint due to its compact design - with no degradation in performance of the key factors identified above.

The major technical challenges are to achieve low velocities close to the bags (avoiding bag erosion), the same or lower pressure losses, and to ensure that the pulse cleaning system has sufficient cleaning power for the longer bags and increased bag area per pulse valve. At the same time, the design should be robust enough to withstand normal variation in service, as well as capable of handling extreme conditions. This paper presents the key aspects of the required design to address gas and dust distribution and pressure drop issues, as well as the pulse cleaning system design and capacity.

2 CLEANING SYSTEM

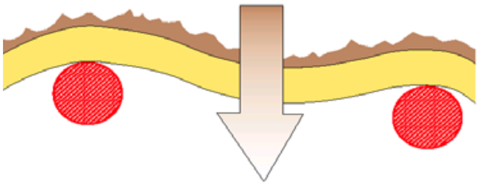
The performance of the bag cleaning system is an essential part of successful FF operation.

The quality of the cleaning system has a great influence on:

- bag life
- gaseous and particulate emission
- pressure drop across filter bags
- total energy consumption

In HRFFs, the bags are cleaned by means of a pulse of compressed air, that is fired axially into the top, open end of the bag. The distribution of compressed air in short pulses is performed by selectively firing a pulse valve, connected to a tank containing compressed air. The pressurized air pulses are supplied to a row of bags by a tube provided with small orifices or nozzles, which direct the jets of compressed air at a high velocity into the tops of the bags. As the air burst travels down and through the bags, the normal flow of flue gas through the bags is stopped (provided on-line cleaning), and a pressure and shock wave is transmitted down the length of the bags. The bags expand, and as their shape changes rapidly from concave to convex, the fabric flexes and the ash layer cracks. As the bags expand to their full circumference and rapidly decelerate, the particles in the ash layer are partly dislodged, due to inertia forces. The dislodged ash cascades down the length of the bags and eventually settles into the hopper located below the bags. See Fig. 1.

The main variables affecting the separation force between the ash layer and the fabric is the fabric acceleration force generated by internal pulse pressure, and the fabric movement distance. The most important design criteria for the cleaning system is to quickly produce a high pressure inside the filter element, by rapidly injecting a large volume flow of pressurizing air against the resistance offered by the filter fabric [5]. A very high rate of volume flow injected into the filter element is essential to achieve the large cleaning forces required for efficient on-line cleaning of long bags.



Bag Cleaning

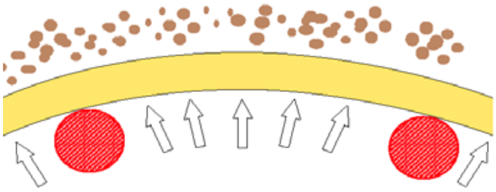


Fig. 1 Gas cleaning and bag cleaning mode

In the APS pulse system design, OPTIPOW®, these requirements are met by using components with low pressure loss, large flow cross section areas, and an optimum geometry, see Fig. 2. This is a well balanced system between pulse valve, volume of air in the pulse tank, pulse distribution pipe and pressure in the pressure tank.

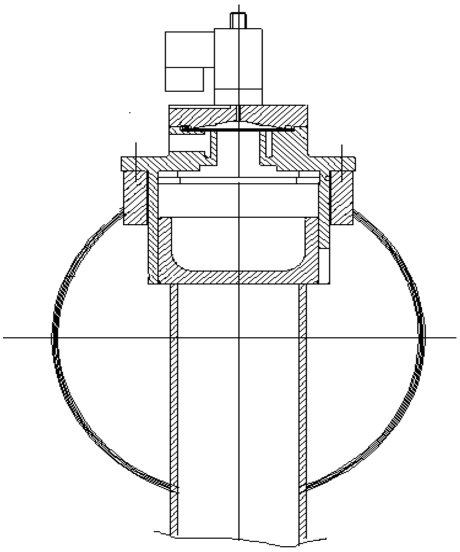


Fig. 2 OPTIPOW® cleaning system with valve, tank and pulse pipe

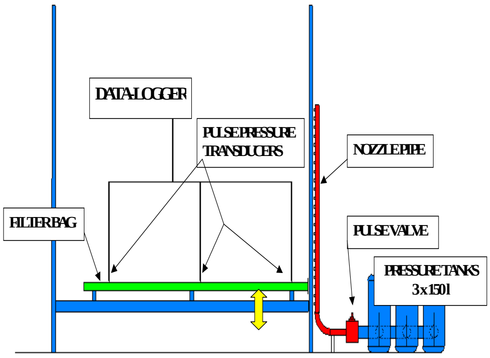


Fig. 3 APS full-scale pulse test rig, Växjö, Sweden

The OPTIPOW® system has been developed and continuously improved by APS during the last 25 years, utilizing e.g. a full-scale pulse test rig, see Fig. 3.

The cleaning system produces a large flow rate of cleaning air. Peak pressure in the bag is reached in about 10 ms. The high cleaning energy can be utilized in several ways, for example:

- cleaning very long bags and many bags at same time
- on-line cleaning is no problem
- cleaning flexibility as required for process changes

The fast action results in a minor stretch of the fabric when it is expanded to the circular form. At the same time no bending of the fabric or friction against the cage occurs in this expanded circular form. Hence, the fast, efficient cleaning will have no negative effect on the bag life. On the contrary, it prolongs the bag life by keeping the fabric clean and in full operation throughout the life of the bag.

When the pulse pressure across the filter bag decreases to a value less than the differential pressure across the filter bag, the return of the bag towards the bag cage starts. The return force is of the same magnitude as the previous cleaning force if the pulse is cut off in a fast manner (short pulse), and will result in an aggressive landing on the cage, with abrasion and increased local stress in the bending zones of the felt.

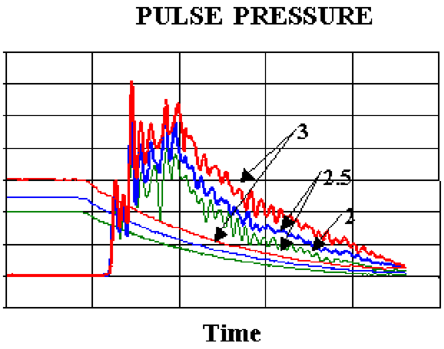


Fig. 4 Tank pressure and pulse pressure vs time

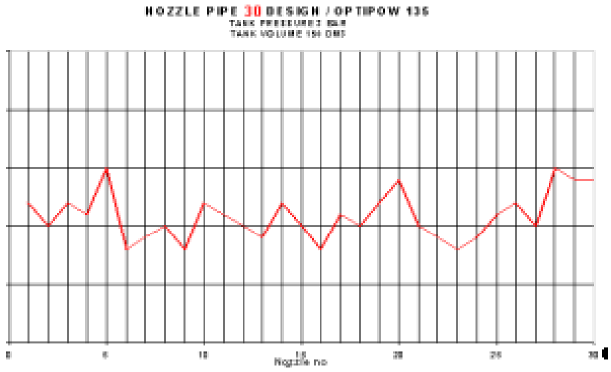


Fig. 5 Pulse pressure for nozzle tube, new FF design

The negative landing effects of the bag on the cage can be very much reduced by decreasing the pulse pressure gradually in a controlled way to achieve a soft landing of the filter bag on the cage, see Fig. 4.

Pulse system performance measurements, to verify sufficient cleaning power for the increased total bag area per valve for the new FF design, have been performed, see Fig. 5. The OPTIPOW® system fulfils the important factors for long bag life by a very effective and even cleaning of all of the bags in each row. This is achieved with very low stress on the bag during the whole cleaning action, expansion and return of the bags to the cages.

3 GAS DISTRIBUTION DESIGN

Proper gas distribution into each bag nest in each compartment of the filter system is essential in order to facilitate on-line cleaning of long bags, and to achieve long bag life. In the OPTIPULSE® HRFF design the raw gas enters the filter compartments from the inlet duct via inlets equipped with guide vanes to distribute the gas towards the upper section of the filter bags. This arrangement creates a downward gravimetric gas flow along the filter bags, assisting ash transport into the hopper at cleaning of the bags. The optimized gas distribution system further ensures that local high approach velocities of the gas/ash mixture are avoided at the filter bags, which is very important to avoid erosion damages on bags and to achieve long bag life.

Means to achieve the new, more compact HRFF design include using longer bags (10 m standard), more bags per cleaning valve, and a new gas flow design for the FF.

Extensive flow modelling work with CFD (Computational Fluid Dynamics) and physical modelling, see Figs. 6 and 7, was performed to develop the gas flow design.

Fig. 6 Physical flow model, Växjö, Sweden

Fig. 7 Filter top with pulse pipes and outlet dampers

The aim of the model testing was the following:

1. Verify and tune the design of the inlet ducting, dimensions, inlet dampers and the design of guide vanes, taking into account the risk of dust accumulations.
2. Verify and tune the maximum gas velocities, approaching the bag nest, at the bag face and in-between the filter bags, not to exceed certain criteria.
3. Minimize the mechanical pressure drop from the common inlet duct to the filter bag plane.
4. Verify the design of the outlet walk-in plenum, including pulse tubes.
5. Verify and tune outlet damper designs.
6. Minimize the mechanical pressure drop, from the bag plane to the common outlet duct, including the restriction of the pulse tubes and the outlet dampers.
7. Verify that the design is robust with regard to varying velocity profiles throughout the system.

Benchmark design criteria with regard to velocities in the inlet ducting and dampers, and velocities close to the filter bags were set, based on APS's experience. Likewise, design criteria for the mechanical pressure drop were established, based on APS's experience.

The flow modelling was performed at a typical gas-to-cloth (G/C)-ratio for power plant applications, 75 m/h (4.1 fpm).

In order to optimize the flow modelling work, physical scale model testing and CFD analysis were planned and performed to complement each other; the physical model was used for detail studies of the flow arrangement inside a single FF compartment, while CFD was utilized mainly for modelling and optimizing of the FF inlet and outlet ducting arrangement for a multi-compartment FF configuration, although CFD modelling of a single FF compartment also was included.

The physical model was built in scale 1:8.44, with perforated plastic tubes used to simulate the filter bags. One compartment of the FF is modelled. In full scale, the bags are 10 m long, with 960 bags per compartment. All existing internals such as guide vanes, dampers and structures have been represented in the model. The model chamber and the chamber bypass duct are connected to a permanent flow exhaust system by separate calibrated venture meters for flow control.

CFD modelling, using ANSYS CFX software, was performed on a single FF compartment model, see Fig. 8, on an inlet plenum consisting of inlet duct and inlets to 3 compartments, with the filter bags simulated as porous boxes, see Fig. 9, and on an outlet plenum consisting of three chambers with pulse tubes, outlet dampers and outlet duct, see Fig. 10. The CFD model reflects a FF design with 2 rows of compartments, each row with 3 compartments, i.e. in total 6 compartments, with 960 pcs 10 m long bags in each compartment.

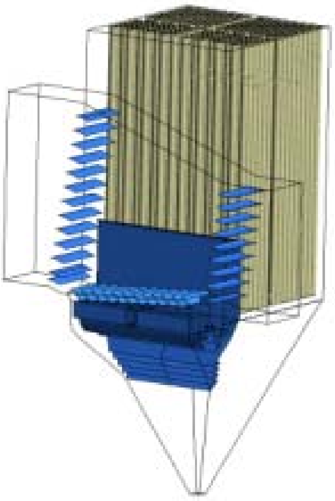


Fig. 8 One chamber CFD-model

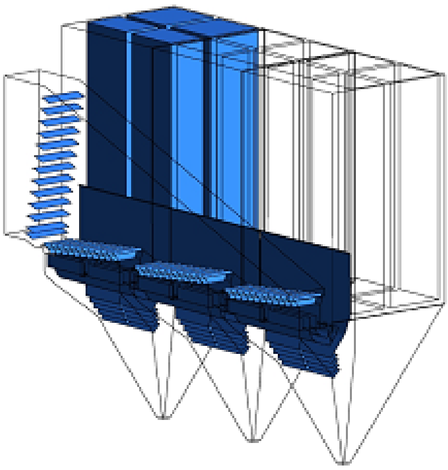


Fig. 9 Inlet plenum CFD-model

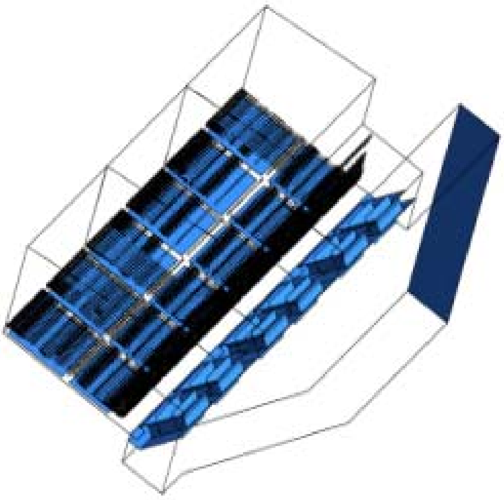


Fig. 10 Outlet plenum CFD-model.

Figs. 11, 12 and 13 illustrate the flow pattern and velocities for the final, optimized FF design.

A gravimetric flow pattern in the bag nest is achieved, and all other benchmark design criteria have been met.

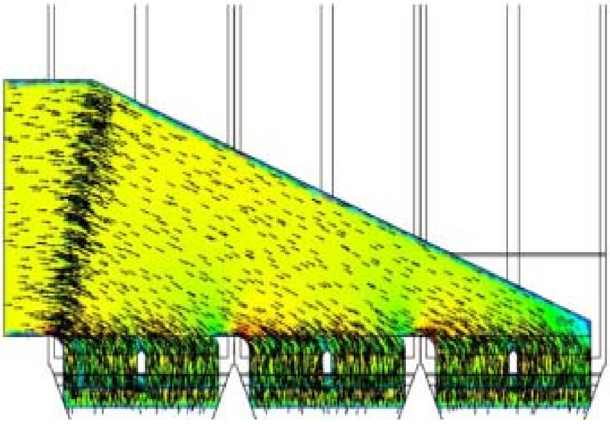


Fig. 11 Flow pattern in inlet plenum. Final design

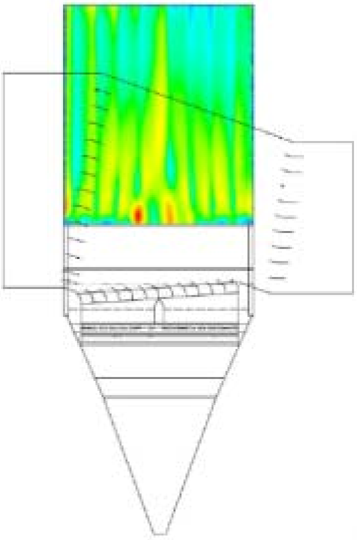


Fig. 12 Velocities close to the bag nest. Final design

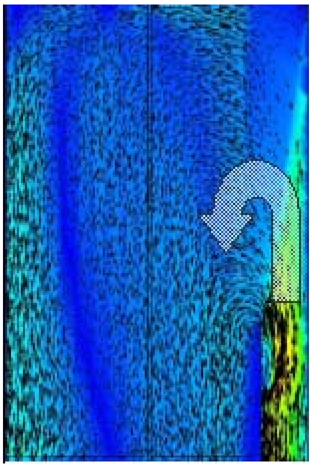


Fig. 13 Gravimetric flow in bag nest. Final design

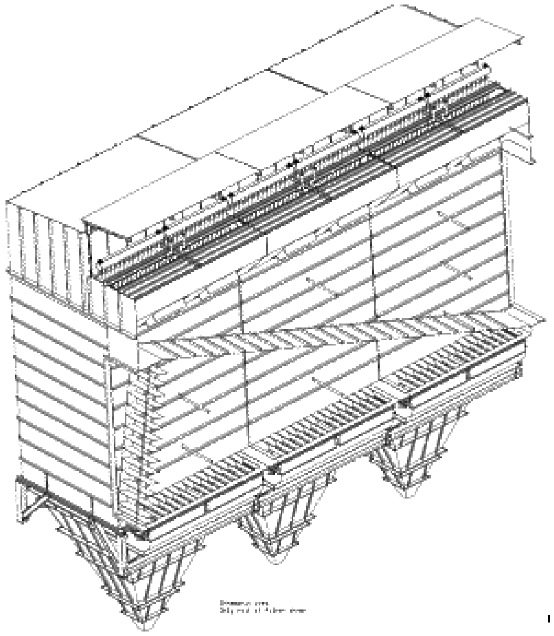


Fig. 14 New FF design

4 NEW FF DESIGN

Catia 3-dimensional parametric design was used to examine various layouts and configurations for the new FF design, and to develop design drawings, see Fig. 14.

The preferred clean gas plenum design is of type walk-in-plenum, see Fig. 15. A top door design is however also available.

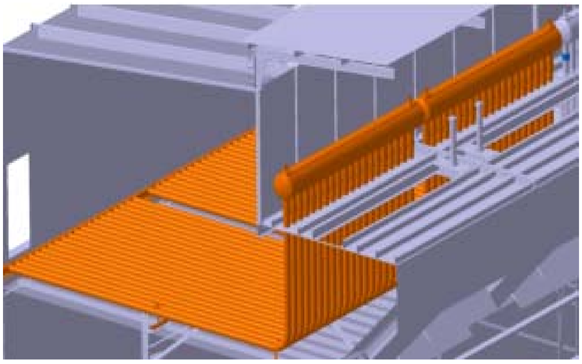


Fig. 15 Clean gas plenum type walk-in-plenum, with OPTIPOW® pulse cleaning system

Comparisons with regard to steel weight and footprint have been made for several large scale sold power plant FFs, utilizing the present standard OPTIPULSE® HRFF design, and the new FF design. Results indicate reductions in steel weight and footprint of around 20% with the new, more compact, design. This translates into significant savings in capital cost.

APS is actively promoting the new design for power applications, and several bids have already been made. A utility customer accepted the design for a new coal fired power plant in the 4000 MWe-5000 MWe size range bid by APS, although the bid was eventually not awarded to APS, due to other circumstances, not related to the FF.

5 CONCLUSIONS

Due to the increasing market demands for HRFFs for power plant applications, suppliers need to provide properly designed, efficient, cost effective HRFF designs. The major technical challenges with more compact and cost effective designs are to achieve low velocities close to the filter bags - to avoid bag erosion- the same or lower mechanical pressure losses, a gravimetric gas flow pattern in the bag nest, and to ensure that the pulse cleaning system has sufficient cleaning power for the longer bags and increased bag area per pulse valve.

APS has recently, by means of an extensive R&D-effort, developed a new HRFF design, meeting these technical challenges and fulfilling all benchmark design criteria.

Comparisons with the present APS standard OPTIPULSE® HRFF design indicate reductions in steel weight and footprint of around 20%, which translates into significant savings in capital cost.

APS is actively promoting the new design for power applications.

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