WWW.MODERNPOWERSYSTEMS.COM SEPTEMBER 2010

Modern Power Systems

COMMUNICATING POWER TECHNOLOGY WORLDWIDE

Testing time for tidal turbines

Membranes filter out compressor problems

Membrane based HEPA air intake filters are proving to be an effective way of reducing compressor fouling and corrosion problems in gas turbines.

Compressor fouling and blade corrosion due to ingress of contaminants in the incoming air (dust, soot, salt, etc) has been an all too common problem for gas turbine operators, requiring frequent compressor washing – which itself has been implicated in some instances of compressor blade cracking, notably in the case of FA machines.

Improved filtering of the incoming air (about 2 million m^3 per hour for a large gas turbine, typically containing around 50 g per hour of dust) is an obvious route to take – bearing in mind that over 99% of atmospheric particles have diameters of less than 1 µm.

But there have been downsides with increased filtration. For example, higher levels of filtering efficiency can result in higher pressure drops, and even the filters themselves can be a source of corrosive particles due to reactions between salt and water within the filter media. Also, conventional HEPA filters require an additional pre-filter stage if adequate lifetime is to be achieved.

Membrane based (as opposed to "conventional" micro or nano fibre glass based) HEPA filters are proving an effective way to steer through these issues, and have been applied to increasingly large gas turbines in the six years or so since they were first introduced by W. L. Gore & Associates, with excellent performance being reported from the field.

Three layers

The GORE® Turbine Filter uses membranes made of ePTFE (expanded polytetrafluoroethylene) and achieves the remarkable feat of increasing the filtration efficiency to the E12/H12 level (which means they keep out at least 99.5% of contaminants at the most penetrating particle size of 0.1 µm or thereabouts), without the penalty of increased pressure drop or shorter filter life.

The key is the 3-layer membrane structure, see Figure 1.

The pre-filter layer removes the bulk of coarse and submicron particles storing them depth-wise, with a minimal increase in pressure drop.

The second layer consists of an ePTFE membrane that removes the smallest particles, water and dissolved salt crystals. As this membrane provides a huge surface area due to its nanostructure it achieves very high filtration efficiency, water tightness and salt repellence.

When becoming wet over long periods of high relative humidity, standard nano-fibre glass media tend to unload accumulated particles and salt (leeching effect) into the compressor, resulting in fouling and corrosion. In contrast, the ePTFE membrane is hydrophobic and therefore not susceptible to water ingress and salt penetration (Figure 2).

Furthermore, its nanometer-scale fibrils and nodes keep the pressure drop at a low level due to the so called slip-flow. In contrast to micrometer-size fibres the drag force on a nanometer-scale fibril is smaller as the molecular movement of the air molecules contributes to the overall airflow. This slip-flow regime results in a lower pressure drop.

The third layer is a high strength backer, which provides high burst strength even when wet. Wet burst tests of cartridge and panel filter elements containing this media show burst pressures well above 6200 Pa.

The combination of these three filtration layers is pleated and integrated into standard cartridge (cylindrical) or panel (square) designs (Figure 3), which can be easily retrofitted into nearly all types of existing gas

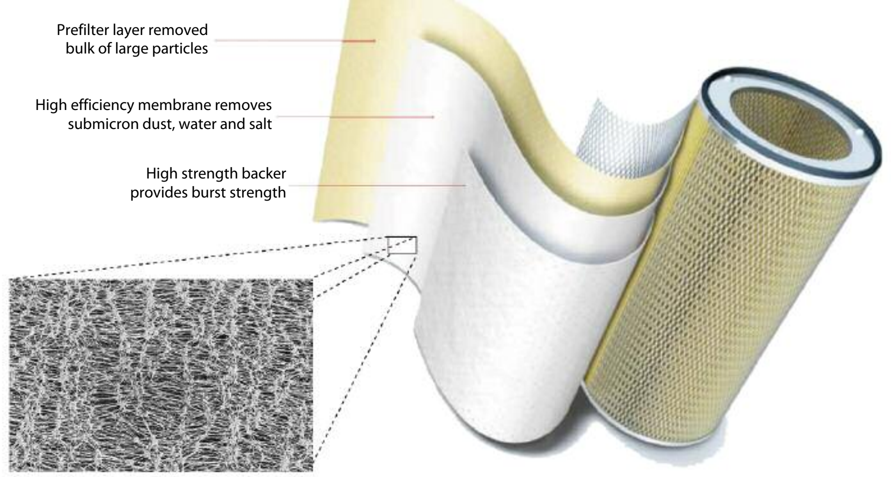


Figure 1. Construction of the 3 layer HEPA filter media with ePTFE membrane

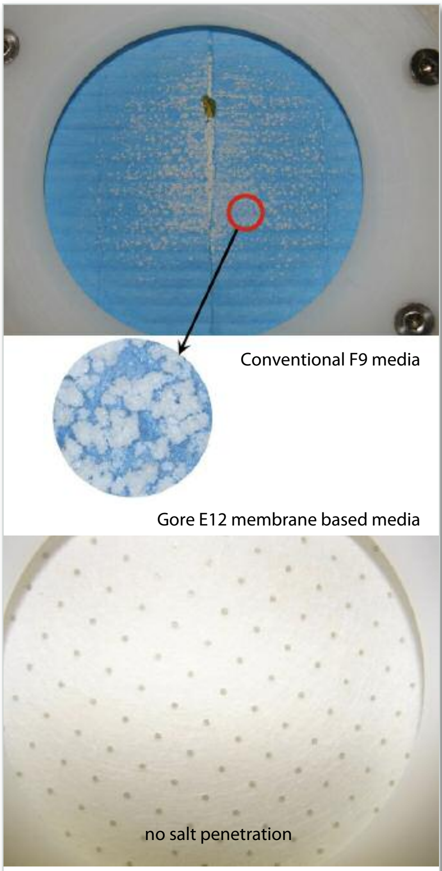


Figure 2. Salt test: 72 h salt fog plus 24 h drying. The Gore membrane based media shows no salt penetration

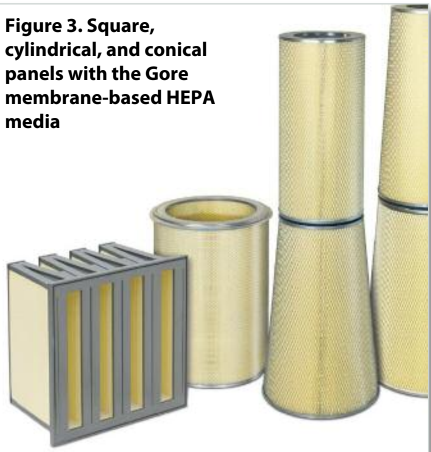


Figure 3. Square, cylindrical, and conical panels with the Gore membrane-based HEPA media

Figure 4. New Z-configuration panel design with the Gore membrane-based HEPA media

turbine filter houses (unlike micro fibre glass media, which are only available in square shapes).

In addition, to take full advantage of the membrane-based technology, a new Z-configuration panel design was developed (see Figure 4). This Z configuration results in about half of the pressure drop (135 Pa at 3400 m^3/h airflow, 180 Pa at 4250 m^3/h airflow) compared with H12 V-shaped panels using micro fibre glass media.

The membrane-based media (be it either Z or V shaped) require only one pre-filter stage, the preferred pre-filter class being G4 or F5, depending on application. No modifications of existing filter houses are needed, such as that needed to accommodate an additional pre-filter stage. Consequently, just about any gas turbine can benefit from H12/E12 HEPA filtration with a low pressure drop and a reasonable filter life-time.

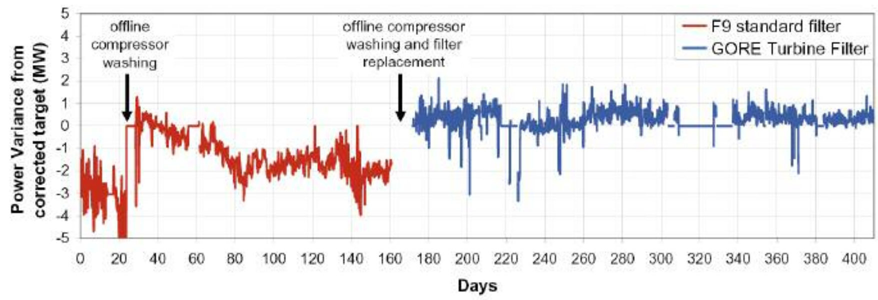
How are the membrane filters performing in the field?

Installations of GORE® Turbine Filters containing the new membrane-based media go back to the end of 2004, initially at relatively small facilities, and their performance has been extensively monitored.

Figure 5. Used compressor washing fluids from two adjacent GE LM6000 turbines. Left: 1st turbine after 1450 operating hours with F9 rated nano fibre filters. Right: 2nd turbine after 2500 operating hours with the membrane based Gore filter

Figure 6. Boroscope picture of compressor section of LM6000 fitted with Gore filter, after 10600 hours, showing totally clean blades

Figure 7. Power output variance from corrected target. Red: conventional F9 filter with 2 offline washings. Blue: Gore H12 filter without any washings



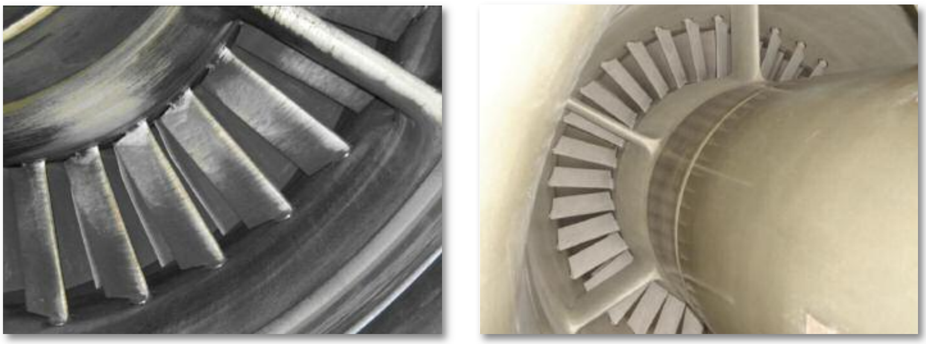
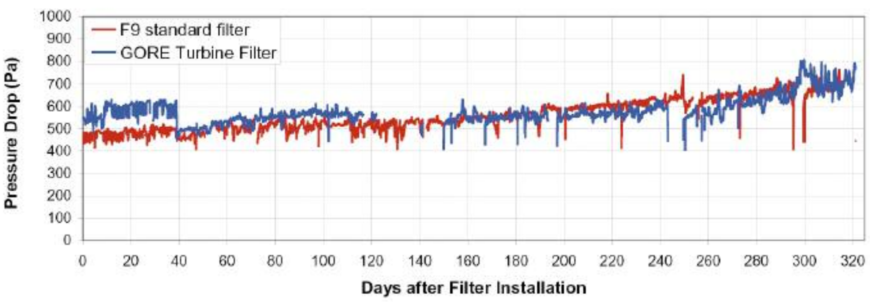


Figure 8. Compressor running with F9 filter, left, and with Gore H12 filter, right

Figure 9. Total inlet pressure drop over time, F9 filter vs Gore H12 filter



Remarkably, all sites have reported the elimination of compressor fouling and a filter life similar to the F8 or F9 rated cartridge filters used before.

According to Wilson Poon, Research & Development leader for GORE® Turbine Filters, “customers who installed the new technology experienced within a matter of weeks significant power output and efficiency increases relative what they would have been with their incumbent filters...due to capture of the submicron particles by the filter’s membrane layer.”

TransCanada experience

Gore worked with TransCanada Corporation to field test the new filter in a direct comparison with a nano fibre filter in identical LM6000 turbines.

After 1450 operating hours, an off-line wash was performed on the compressor section of the turbine that had the nano fibre filters. The resultant used wash fluid was black, indicating significant fouling of the compressor. However, after 2500 hours of operation, an off-line wash performed on the turbine with the Gore filter yielded white effluent, with no evidence of particle contamination. Figure 5 illustrates the point. Despite running the Gore installation nearly twice as long as the other one before the wash there is virtually no dirt to wash off during the soak washes, hence the milky white wash fluid.

Rick MacDonald, plant manager at TransCanada Corporation’s Grandview power plant in New Brunswick, sums up his experience thus: “Prior to installation of the new filters, we were required to offline soak-wash each of our turbines every five to six weeks, and we typically experienced up to 1 MW of power loss on each 44 MW turbine between washes. With the Gore filters, we now operate for four months between washing, and we do not see any power loss at all. In fact, the turbine power output and heat-rate have held steady for the entire 18 months of filter operation so far, and we expect to get two or more years of total service life. What a difference in performance!”

He also notes that the installation of the filters was simple – a direct replacement “of our old filters with the Gore filters” – and that “use of the filters has resulted in a clean turbine compressor section from initial installation to-date.”

Figure 6 shows the compressor section of the LM6000 fitted with the Gore filter, after 10 600 hours of operation. This explains why the wash fluid in Figure 5 is white. The blades appear unsoiled and the compressor section seems “to be as clean as the day we installed the Gore filters,” says Rick MacDonald.

RB211 in the UK

Another example is a Rolls-Royce RB211 31 MW gas turbine running in baseload at an industrial site on the western coast of England (as reported, along with the other case studies mentioned below, in a paper* presented at PowerGen Europe, Amsterdam, June 2010). The single stage filter house contains 112 pairs of conical and cylindrical cartridges and was originally equipped with standard F9 rated filters.

Operating the gas turbine with this level of filtration, the operator, E.ON UK, experienced significant power loss, up to 3 MW before an offline washing due to compressor fouling (left side of Figure 7). The left side of Figure 8 shows the fouled compressor resulting from operation with the

F9 filtration. Offline washing needed to be scheduled about every 2 months.

In March 2008, GORE® Turbine Filters were installed, including an additional pre-filter wrap. When running the gas turbine with these H12 cartridges neither compressor fouling nor a drop in power output was observed (Figure 7, right hand side). So no compressor washings were required. Figure 8, right hand side, shows the clean compressor after about 2000 hours running with the Gore H12 filters and no washing.

Looking at operating life, the new Gore H12 filters exhibited a pressure drop over time comparable with the previous F9 rated cartridges (Figure 9) – but also eliminated compressor fouling, with no observed reduction in compressor efficiency and gas turbine power output capability.

Figure 10. Performance data for Gore cartridge pair installed on GE Frame 9FA, Spain

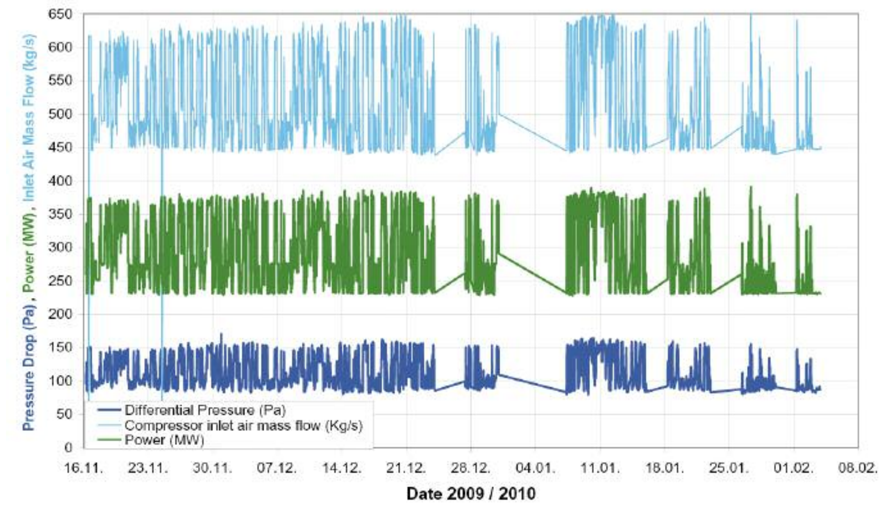


Figure 11. Performance data for cartridge pair installed on a Siemens SGT-300, Middle East

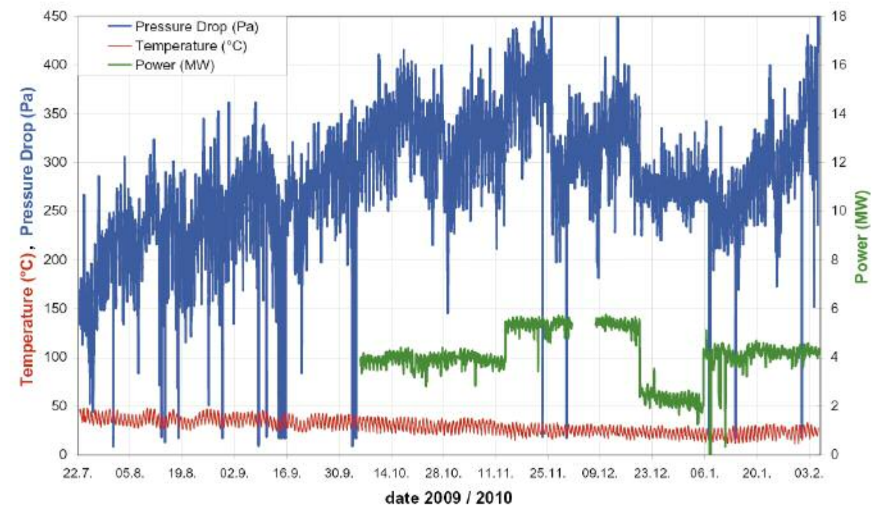
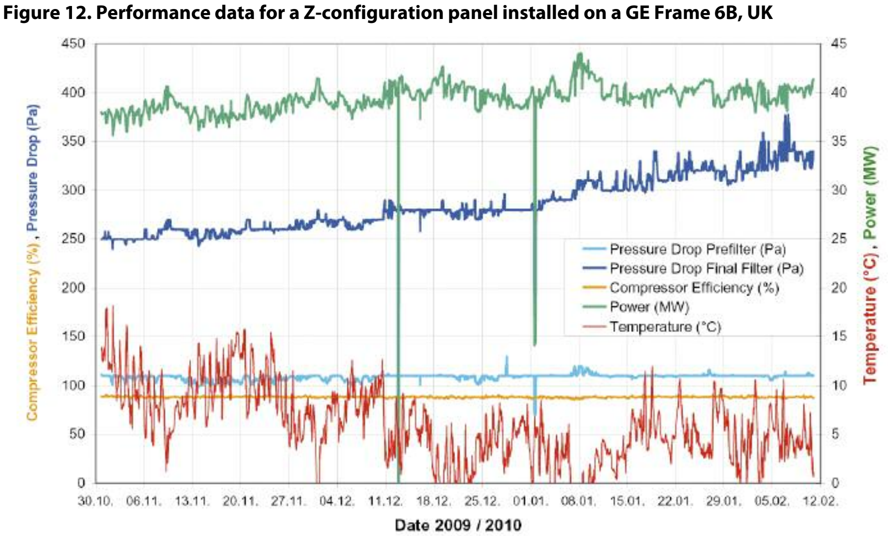


Figure 12. Performance data for a Z-configuration panel installed on a GE Frame 6B, UK



9FA in Spain

Some 700 H12 Gore cartridge pairs were installed at a GE Frame 9FA in Spain in November 2009, at an industrial site about two km from the Mediterranean Sea. The operator had experienced corrosion and compressor fouling with the previously installed F9 filters.

After installation of the new filters, no such problems have been encountered. There has been no decline in power output capability due to the compressor, and no significant increase in pressure drop across the filters.

Figure 10 shows performance data for the first three months following the change of filters.

SGT-300 in the Middle East

In July 2009 thirty cartridge pairs in the filter house of a Siemens SGT-300 gas turbine located in a desert area in the Middle East were replaced with the Gore membrane based filters. Due to the large amount of coarse dust in the air, particularly during sand storms, pulse cleaning is applied at this site, with two cartridge pairs subjected to a 6.5 bar compressed air pulse every 20 seconds to release accumulated coarse particles.

Monitoring data since the installation of the new filters is shown in Figure 11. There was no decline in efficiency due to compressor fouling, while the filter pressure drop increased by about 200 Pa over 7 months.

6B with new Z panel

The advantages of the new Z-panel design have been demonstrated at a GE Frame 6B gas turbine located at an industrial site in the UK.

With the previously used combination of a G4 pre-filter stage and F8 filters clipped onto the H10 final filter stage, the operator needed to perform about 12 on-line and 4 off-line washings per year.

Compressor fouling caused a drop in power output of about 10%, or 4 MW, between off-line washings. In October 2009, the filter house, which has 120 panels, was equipped with 78 panels of the new Gore Z-shaped design and 42 V-shaped panels at positions where the Z-panel was difficult to install because of space restrictions. All the new panels employed the new membrane-based media, while the pre-filter stage was equipped with the same G4 bag filters as before.

Figure 12 shows performance data following the change of filters. No compressor fouling, no compressor efficiency loss and no decline in power output were observed. The monitored pressure drop of the final filter stage shows an increase of about 80 Pa within 3.5 months, while the pressure drop across the pre-filter stage remained constant.

Award from AFS

In April 2010 the American Filtration and Separations Society gave W. L. Gore & Associates a New Product Award for development of the filter, recognising an "innovative product that significantly improves fluid-particle separation."

*** Marc Schröter, W. L. Gore & Associates GmbH, Germany and Peter Hall, E.ON UK,** *Field experience with advanced membrane-based HEPA filtration* MPS