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STRATEGY FOR SELECTING OPTIMISED TECHNOLOGIES FOR GAS TURBINE AIR INLET FILTRATION SYSTEMS

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ABSTRACT

With continuous advances in gas turbine technology, wider breadth of fuel quality burnt and ever growing expectations of; longer life, higher efficiency and reduced maintenance requirements, the filtration of the air entering the gas turbine (GT) has never been more important to meeting its operational requirements.

Gas turbines are used throughout the world in an ever increasing diversity of application and environment. This presents a number of challenges to the air filtration system, that require unique solutions for each subset of environment specific challenge, gas turbine platform technology and fuel quality being burnt.

This paper discusses the importance of air filtration to a modern GT and how this has changed over time and it's shifting operational requirements. It explores the challenges facing the air filtration system presented by the different; environments, GT technologies and fuel quality. The paper details what approaches and filtration technologies are currently used to address these challenges, with strengths and weaknesses explained as appropriate, to finally present a strategy for specifying an optimized filtration system to meet the challenges of the modern GT.

NOMENCLATURE

GT – Gas Turbine
µm – Micron or micrometer
FOD – Foreign Object Damage
HEPA – High Efficiency Particle Arresting
LNG – Liquefied Natural Gas
NaCl – Sodium Chloride
H2S – Hydrogen Sulphide
CFD – Computational Fluid Dynamics
DLN – Dry Low NOx

INTRODUCTION

With the wide spread availability of fuel gas and their economic attractiveness, GT's have become standard for many applications including; propulsion, power generation (power gen), mechanical drive (pumping and compression) and steam generation.

Today a GT is a high precision, highly optimized machine and as such is sensitive to contaminants in the air or fuel that may pass through it. The massive amount of air passing through a GT means that even with a very efficient filter system, appreciable amounts of contamination will still reach the GT. For example, a GE Frame 9 GT will consume all the air within Wembley Stadium in 2 hours. As a result of this, it is essential that an appropriate and effective filtration system is installed on the GT intake. However the selection of this can depend upon a considerable number of factors which will be explained through this paper.

The use of an incorrect filtration system can lead to the following four main types of issue [2][5][8], which may result in reduced performance or costly repairs due to failure:-

Erosion

Relatively large (typically >10 µm) particles or droplets impact the blades within a GT, over time this can change their aerodynamic shape, or create high stress points via pitting, which can lead to crack formation and catastrophic failure.

Corrosion

Corrosive substances, even in small quantities, when entering a GT can cause substantial damage. In the "hot sections" of the GT this is particularly true of sodium which combines with sulfur in the fuel at high temperature and in the "cold sections", chlorides and sulphates which combine with water to form acids. Both cause blade pitting with similar failure modes to erosion.

Fouling

Small particles adhere to the blade surfaces, changing the aerodynamic shape and affecting it's performance. Primarily this affects the compressor section of the GT and may be caused by sticky particles, or by the coating of a sticky substance such as a hydrocarbon vapour, which then promotes the adherence of non-sticky particulate. This is typically not permanent and most often alleviated by performing a compressor wash, which to be most effective requires the GT to be shutdown.

Particle fusion and Plugging

Particles such as sodium chloride or potassium chloride melt in the hot stages of the GT forming molten contaminants which then adhere to the internal surfaces of the GT and change the profiles of blades affecting their performance, or block critical cooling passages causing thermal fatigue and eventually catastrophic failure.

CHALLENGES PRESENTED BY THE ENVIRONMENT

The contaminants present in the global environment can be broadly broken down into the following five categories:-

1. **Salt:-** Most commonly in the form of Sodium Chloride (NaCl) and generally sourced from the sea. Depending upon the relative humidity, this contaminant may be in the form of a droplet aerosol, a dry particulate, or a partially solid / wet sticky dust [1][6][7]. This must be remembered when specifying a filter system, as even once captured, it will change state and may render its capture mechanism ineffective. This phenomenon is often termed salt leaching or percolation.
2. **Bulk Water:-** Significant quantities or "bulk" water can be a challenge for a filtration system and can come from a number of sources. In tropical environments, this can be due to driving rain. In coastal and marine locations it can be in the form of spray from breaking waves.
3. **Dust:-** Dust is always present in the environment and every location will have a unique type and composition that will change over time with seasons etc. This can be in low or extremely high concentration levels. It can range from very dry and inert, such as sand, to very oily and sticky particles, such as carbon. This can also range in particle size from very fine (<2 µm) to coarse (>2 µm).
4. **Snow / Ice:-** In cold weather locations, snow and ice can be a challenge, causing blockage of filters and possible risk of FOD to a GT. Icing can be predicted, which comes in several forms that can present challenges. Snow is a complex substance that is not easy to predict either the formation of, or it's settling characteristics.
5. **Vapour:-** In addition to liquid and solid states, contaminants can be in the form of a vapour. There are many sources of vapour, such as un-burnt hydrocarbons from combustion processes, hydrogen sulphide (H_2S) from drilling operations etc. or even mist and fog. These can present risks to the GT, such as cold end corrosion, or create a real challenge to the filter system, such as dust swelling in fog and mist.

To either remove or control each of these contaminant types requires a different filtration approach. Many if not all of these types of contaminant are present at most locations throughout the world, which means that an effective and optimized filtration system for a given location requires the successful combination of each of these approaches.

FILTRATION TECHNOLOGY CURRENTLY USED TO ADDRESS ENVIRONMENTAL CHALLENGES [2][5][6]

Salt

Two approaches are generally used to provide protection against salt.

Vane / Coalescor / Vane (VCV) System

For marine and offshore installations, this is the system of choice[3][4][8][9], with the large majority of GT installations in this environment protected by this type of system.

This principally comprises of a three stage system.

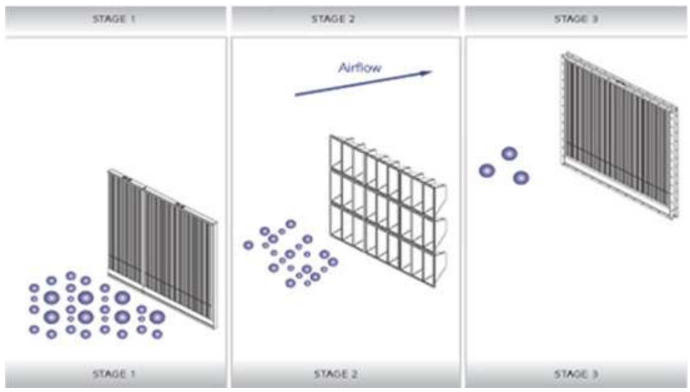


Figure 1: Vane / Coalescor / Vane System

Stage 1 is a vane separator. This device consists of a large number of vertically oriented vanes, which are plates formed to a certain shape, which when pitched apart form a tortuous path to the airflow. This has the effect of inertially removing water droplets, as they cannot traverse the tortuous path without impacting a vane surface and being captured. Vane separators are typically efficient at removing droplets down to 15 µm in diameter. The function of this first stage is to remove "bulk water", which is often present in these environments and which can lead to overwhelming of the downstream stages if not addressed.

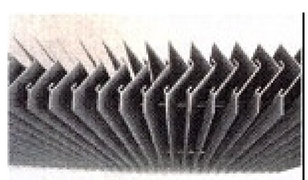


Figure 2: Typical vane separator

Stage 2 comprises of a coalescing filter. In true marine applications, this is most often a very low dust efficiency filter, which is only effective at coalescing small droplets into larger ones. When the unit is this close to the sea, the major source of salt will be in droplet form.

In offshore applications, this stage is often split into two different filter types, a pre-filter and a final high efficiency dust filter, both of which also act as coalescors, while also providing a good level of particulate filtration to remove dust as well as any salt particulate.

The primary purpose of this stage is to coalesce the small droplets of salt aerosol that pass the first stage vane separator, into larger droplets, which can then be removed by the third stage vane separator, a critical part of the system, as the drops are now much bigger than the efficiency limit of 15 µm.

Hydrophobic Filter System

This type of filter system is generally a standard dust removal configuration (see dust/static later) which is very effective at removing dust and salt particulate. The major difference over the standard dust system is that the final stage of filters have been designed such that they are "hydrophobic"[5] within the likely operating pressures of the system. This means that the final filter will not let water, i.e. salt droplets, pass through it.

For coastal applications, this is the system of choice, as wet salt levels are generally lower and it is easy to combine with a standard filter system to address the other types of contaminant in this application.

Benefit	**VCV**	**Hydrophobic**
Wet salt removal	+	-
Dry salt / dust removal	-	+
Compactness	+	-
Simplicity	-	+
Cost	-	+

+ = Most favourable **-** = Least favourable

<u>Bulk Water</u>

Rain Hoods and Louvres

The principal of rain hoods and louvres is the same, as a louvre is essentially a cluster of small weather hoods. They present an obstruction surface to falling or driven water droplets, however, they only affect large droplets, with smaller ones able to follow the airflow path. Often large droplets that do impact on the obstructive surface shatter into smaller drops which then continue downstream and so are generally only effective for light rain.

Vane Separator

The principal of a vane separator has already been discussed earlier. This device is very effective at removing both large and relatively small droplets, and with the large surface area of the vanes, can deal with significant quantities of "Bulk" water.

Benefit	**Vane**	**Hood / Louvre**
Capacity for water quantity	+	-
Droplet size efficiency	+	-
Compactness	+	-
Cost	-	+

+ = Most favourable **-** = Least favourable

<u>Dust</u>

The vast majority of GT filtration systems today use media filters to filter dust. They are generally deployed in two different types of configuration, which is driven by the concentrations of dust loading expected.

There are some technologies other than media type filters available, such as inertial separators and wet scrubbers, but their use is virtually nonexistent today, or at least reserved for very specialist applications, such as hover craft intakes.

Static Filter

For low / average dust concentrations, a static filter system is utilized. This generally comprises of a number of filter stages with progressively increasing filter efficiency, see figure 3. In this configuration, once a filter is fully loaded, it is removed and disposed of. The use of several stages of filter, allows a form of pre-filtration to be incorporated, to extend the life of the high efficiency final filters, which might otherwise be overwhelmed with large particulate.

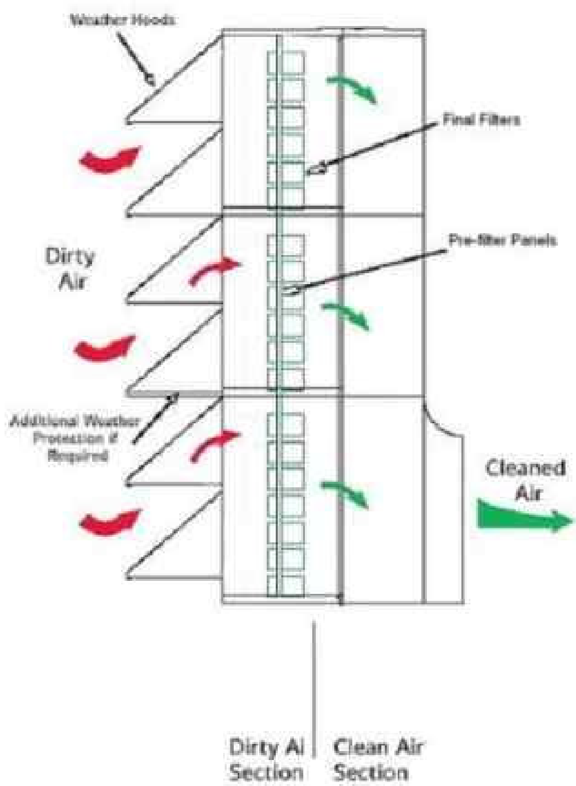


Figure 3: Typical Static Filter System

Often pre-filters are changed with the GT still running, as there remains a filter downstream to provide protection. Final filters are virtually always replaced with the GT shutdown, as there would be nothing further downstream to protect the GT from damage during the filter change out.

There are numerous filter types that can and are used as static filters, such as; bags, minipleats, cartridges or panels. They all essentially perform the same function, just with subtle advantages and disadvantages over each other.

Pulse or Self Cleaning Filter

For high dust concentration applications, a self-cleaning filter system is generally required to provide adequate filter life.

The most common form of this is the "Pulse" filter system, see figure 4. This generally consists of cartridge type filters attached to a tube sheet, behind which is a compressed air pulse system, which periodically provides a blast of compressed air at the filter, in the opposite direction to normal airflow, to cause the dust on the filter to release and there by "cleaning" the filters.

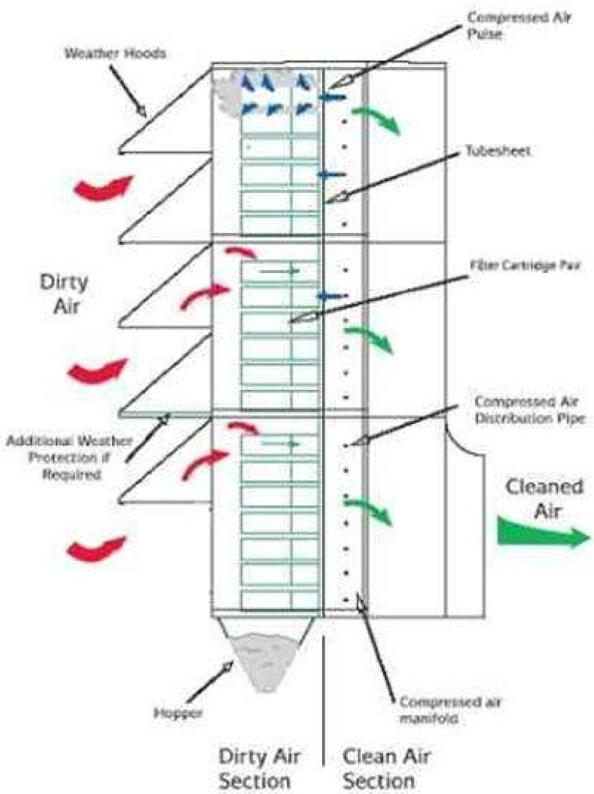


Figure 4: Typical Standard Pulse Filter System

In very high dust concentration locations, such as the desert, an extreme version of this known as the "upflow", see figure 5, is generally used as it has been found to be more effective.

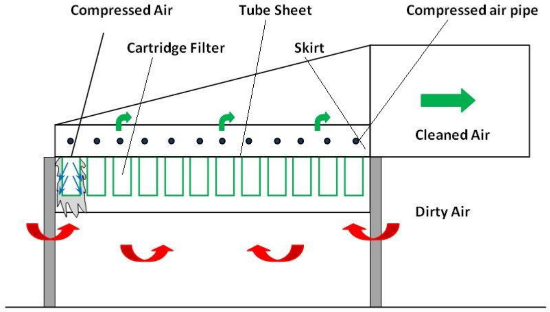


Figure 5: Typical Upflow Pulse System

Benefit	**Static**	**Standard Pulse**	**Upflow Pulse**
Initial dust efficiency	+	-	-
Filter life	-	0	+
Sensitivity to fog / mist	+	-	-
Compactness	+	0	-
Cost	+	0	-

+ = Most favourable 0 = Unbiased - = Least favourable

Snow / Ice

Snow Hood

By its nature, snow tends to follow the wind and only settles when wind speed is very low. The snow hood try's to take advantage of this fact by reducing the velocity of the air entering the GT inlet and thereby reducing the quantities of snow drawn in to manageable levels.

This is generally true if a single snow hood is used, however for many GT types, this can simply be too large to be practical. In such a situation it is often the case to use multiple snow hoods mounted one above the other. Unfortunately, this negates the effect of reduce air flow velocity and so is only effective in light snow.

Pulse Filter

For true heavy or prolonged snow conditions, the most effective filter system to prevent blockage is the use of an upflow pulse type filter, which successfully reduces the airflow velocity as well as providing a self-cleaning system to remove it.

For icing type applications, the use of a standard pulse type filter system has proven to be effective at removing ice formation on the filters.

Inlet Heating

Inlet heating is often utilised in cold environments to prevent icing of the filters in addition to downstream components such as; the silencer and GT inlet guide vanes.

This type of system generally requires significant heat energy and this can be provided from a number of sources, such as; GT compressor bleed air, recovered heat from the exhaust, or GT enclosure ventilation air etc.

For anti-icing this can be effective, but for snow, the effectiveness can be unpredictable, with the anti-icing system converting snow into super chilled water, which can be as difficult to deal with as the original snow, freezing onto any cold surface it comes into contact with.

Benefit	**Snow Hood**	**Upflow Pulse**	**Inlet Heating**
Effectiveness vs. Ice	-	0	+
Effectiveness vs. Snow	-	0	+
Cost	+	-	-

+ = Most favourable 0 = Unbiased - = Least favourable

Vapour

Today an "all purpose" vapour removal system does not exist that can be practically applied to a GT.

Coalescor

To reduce the effect of dust swell on the pressure loss of a filter during periods of mist and fog, it has become common practice to install a coalescors stage upstream of the filter stages, to coalesce a portion of the mist / fog droplets and drain them away.

Activated Carbon Filter

Over the years, the use of activated carbon has been explored for the removal of vapours, however the challenge remains that a GT continuously draws in enormous quantities of air and this can lead to the need to change the activated carbon frequently, which can make this impractical.

Most of the filter technologies that were discussed in this section can be integrated together to form a filter system that can manage multiple types of contaminant.

STRATEGY FOR SELECTING THE MOST APPROPRIATE FILTRATION SYSTEM FOR A GIVEN ENVIRONMENT

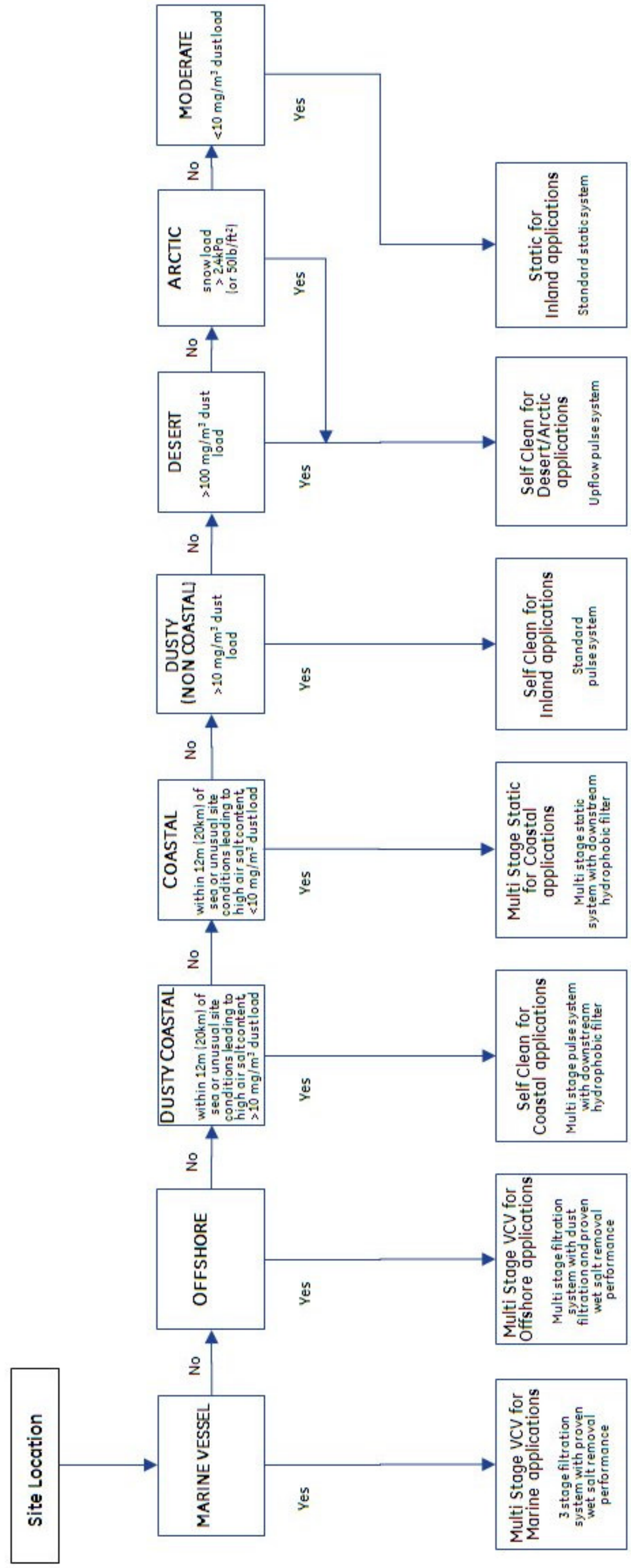
From a filtration point of view, the global environment can be broadly broken down into seven major types, with two sub types that can apply to all:-

Environment type	Salt levels	Dust levels	Other challenges
Marine	High	Low	Bulk water
Offshore	High	Medium	Vapours
Coastal	Medium	Medium	Vapours
Dusty	None	High	Vapours
Dusty Coastal	Medium	High	Vapours
Desert	None	Very High	-
Moderate	None	Medium	Vapours
sub... Arctic	-	-	Snow and Ice
sub… Tropical	-	-	Bulk water

To determine the environment type and filtration requirements for a given GT application the following seven questions should be answered:-

Characteristic	Evaluation Criteria
Coastal / Corrosive	Distance from a source of salt
Water Levels	Max rainfall Instances of fog
Dust Levels	Extremely high High Seasonally high Low
Particulate Type	Dry / Sticky
Mean Particulate Size by Number	<2 microns / > 2 microns
Min Temperature	< 40F
Snowfall	Inches per year

The flow chart below, which has been created based on many years of lessons learned, can be used to determine the most successful "major filtration system type" to be used. Consideration of the two sub-types can then be used to determine additional required options, as well as the second flow chart explained in later sections of this paper.



Following selection of the "major filtration system type", the specific performance characteristics of the individual filter elements to be used can be optimized by considering the preceding sections and strategy described below in the proceeding sections of this paper.

ADVANCES IN GAS TURBINE DESIGN

Over time, the design of GT's has advanced significantly. They are now much more; powerful, reliable and efficient, but these advances have also made the modern GT complex, running within tighter operational limits and are therefore less tolerant or forgiving of abuse.

From an air inlet filtration selection point of view, GT's can be classified into the following four major classes:-

Previous generation or "Low tech"

These machines are first or second generation introduced predominantly in the 1960's and 70's. They have pressure rations and firing temperatures that are relatively low when compared to modern GT's, with simple analogue control systems.

Examples of these would be: Siemens TB5000, Rolls Royce Avon, Solar Centaur and GE Frame 6B.

Strengths

- Robust, plenty of margin in components, large clearances, will take a lot of abuse before failure.

Weaknesses

- Low thermal efficiency so fuel costs high.
- Higher levels of emissions, designs such as low NOx not yet developed.
- Lower reliability, due to controls technology in its infancy and lack of significant operating experience. Preventative maintenance difficult to plan, technology not yet available for self-diagnostics etc.

Recent generation or "Medium tech"

These machines were developed in the 1980's. They run with higher pressure ratios and utilize advanced materials and technologies such as single crystal blades, with advanced cooling pathways to run with higher firing temperatures. Control systems are more advanced with sensor fed microprocessor control.

Examples of these types of GT would be: Siemens Tornado, Rolls Royce RB211, GE LM2500, Solar Mars and GE Frame 9E. This group of GT's currently represents the largest proportion of GT's used today.

Strengths

- Higher fuel efficiency, resulting in lower fuel costs.
- Robust, some margin still in components, will take some abuse before failure.
- Longer life components, lessons learned from running previous generation of GT's incorporated into design and advance in materials improving component life.
- Advanced solid state controls enabling self-diagnostics and predictive maintenance.

Weaknesses

- Emissions levels still high compared to current generation, although better than previous.
- Generally restricted to small range of fuel types.

Current generation or "High tech"

Developed in the 1990's, this type of machine has been generally designed with the aid of the latest computer modeling software such as computational fluid dynamics (CFD), which has led to a more optimized design, with all aspects pushed further to the limits of performance and manufacturing capability. These generally run with increased pressure ratios and further optimized DLN combustion and cooling pathways to push up the firing temperature still further, along with further reduced clearance tolerances. Extensive use is also made of the latest digital, high tech controls.

Examples of these types of GT include: Siemens Typhoon, Rolls Royce Trent, GE LM2500+, Solar Titan and GE Frame 9FB.

Strengths

- High fuel efficiency, so further reduction in fuel costs.
- Further lessons learned improving accuracy of predictive maintenance.
- Fast sensors and controls enabling real-time adaptive control of the GT process, optimized through the range of operation. Data available across the Internet for remote monitoring and diagnostics.
- Advanced, computer model optimized combustion design to reduce emissions, with advanced low NOx.
- Generally designed for efficient operation with wider range of fuel types.

Weaknesses

- Components optimised with less margin in their design, so less tolerant of abuse than previous generations, requiring greater levels of protection and care.
- Maintenance of ancillary equipment such as filters is now more critical.

Next Generation or "21st Century"

To achieve simple cycle efficiencies beyond todays 40%, requires the use of modified thermodynamic cycles by the inclusion of elements such as; pressure pre-boosters, intercoolers and recuperators, as well as the use of super critical steam cooling etc.

Examples of these "Next Generation" engines typically developed in the 2000's include; Rolls Royce WR21, GE LMS100 and GE Frame 9H

Strengths

- Higher fuel efficiency so more economical.
- Further reduced emissions of NOx and CO_2
- Flatter power curve vs. ambient temperature, so less dependent upon ambient conditions.

Weaknesses

- Little experience or expertise with the new technologies, so a new learning curve for OEM's and End Users alike.
- More complex and operation critical ancillary systems requiring increased monitoring, redundancy and maintenance.

Each of these four GT technology groups tends to require a different level of air quality entering the machine and as such, the performance of the air filtration system is potentially different for each.

THE EVOLUTION OF INLET FILTRATION RESULTING FROM HISTORIC CHALLENGES WITH GT'S

Since the introduction of GT's, five common major operational issues have been experienced which have led to changes to the design of the GT and inlet air filtration system:-

Erosion Failure

When GT's were first introduced into non flight applications, filtration was applied to eliminate the risk of foreign object damage (FOD) only, which can occur with large contaminant, such as stones, leaves etc. Little thought was given at that time to fine levels of filtration and as a result, erosion was experienced, which shortened engine component life. It was found that to prevent this, a filtration system with high efficiency down to 10 microns in size was required. This requirement drove the use of the first GT inlet filtration systems.

Hot End Corrosion due to Sodium Chloride

As GT's went to sea for the first time, the level of component corrosion was found to have significantly accelerated. This led to the development of the first salt removal systems.

Following the deployment into Warships , GT's then started to be used on offshore platforms. During this same period of time, GT technology developed with the use of higher firing temperatures. For the first time this put the hot sections of the GT into the active zone for hot corrosion due to Sodium and Sulphur. This led to an even greater focus on high levels of salt removal efficiency from the GT inlet air filter system.

Compressor Fouling Nuisance

With the issues of GT component life (erosion and hot corrosion) overcome, focus turned to the efficiency of the GT. Efficiency degradation over time was recognized as being as a result of compressor fouling and as such compressor washing systems were installed to periodically return the compressor to its optimum efficiency. To be effective, this required an off-line wash to be performed, i.e. with GT switched off. For critical applications this can have a significant impact on the operation.

Compressor fouling is mostly caused by small particulate generally less than 1um in size. To reduce this, a further improved filter efficiency is required, with even EPA / HEPA [12] levels of filtration being considered and implemented for some critical and high value GT applications today.

Cold End Corrosion Failure

There is evidence that some of today's very modern GT's are suffering from reduced component life in the cold section of the GT for the first time. This is due to the effect of corrosion, on the highly optimized components, which in this case is primarily caused by contaminants in vapour form. To date, the removal of this form of contaminant has not been a design requirement for GT inlet filtration systems, but in the future it is much more likely to be.

Hot End Corrosion Again due to Sour Fuels

The recent more abundant use of "sour" fuels has led to a requirement for increased salt removal efficiency, beyond that typically deployed before. This is becoming an ever increasing requirement as more of this type of fuel is being used.

EFFECTS OF GT DEPLOYMENT AND OPERATIONAL STRATEGY ON FILTRATION SELECTION

The end users deployment strategy and mode of operation for GT's has changed over time, in line with the particular strengths and weaknesses of each of the above GT groups.

Five major aspects of the different strengths and weaknesses of each GT group have a particular influence on the selection of the appropriate filtration system:-

Reliability - Availability of GT for Maintenance Operations

When GT's were first used, only the "previous generation" types of GT's were available, and one of their weaknesses was reliability. This typically led to multiple GT's being installed for a given application, with a degree of over capacity utilized, such that it was virtually always possible to operate to the full requirements of the application, with at least one GT switched off, in a "backup" role.

This meant that maintenance could be carried out on any one of the GT's at any time, as required, and that the application would remain unaffected if one GT came off-line due to an unexpected issue.

In time, as the GT types deployed have moved through the generations with much higher and predictable reliability, the deployment of "backup" GT capacity has become virtually non-existent. This means that if a GT needs to come off-line for a maintenance requirement, this now affects the application for which the GT is being utilized and therefore ideally has to be planned for ahead of time. This trend has the following effect on the selection and design of the air filtration system:-

Filter life

With excess GT capacity available, shutting down to perform a filter change has no operational effect on the application for which the GTs are being used. This means that the life of the filters is unimportant to the application, with the only consideration being the replacement cost, rather than the impact on the application. When no "backup" GT capacity is available, then the life of the air filters now becomes a critical characteristic to the application that the GT is being used for.

Ideally the life of the filters should be sufficient to enable the GT to run between other scheduled maintenance requirements without requiring a filter change, such that the filter change again becomes non critical and can be performed at the same time as other more critical scheduled maintenance.

Filter efficiency

With non-availability of "backup" GT capacity, fouling of the GT compressor now becomes a critical factor. Ideally to eliminate any effect on the application for which the GT is being used, all nonessential maintenance, such a compressor washing, should only be carried out at a scheduled outage. To reduce compressor fouling rate to achieve this requirement, more efficient filters are required which becomes an additional filtration performance consideration.

Generally, increasing the efficiency of filters has the effect of reducing their operational life and so the right compromise between filter life and filter efficiency will have to be achieved to optimize the two factors detailed above.

Robustness – GT Component Sensitivity to Contamination

Over time, as the different generations of GT have been developed, the components within the GT have become more optimized which has led to them being more sensitive to the effects of contamination and corrosion. This has the following effects on the selection of an appropriate filtration system:-

Particulate Removal Efficiency

The fouling of blades with contaminants can have a significant impact on the efficiency of a modern GT which has led to a drive for more and more efficient air filters to reduce this effect over time. An increase in the dust removal efficiency will reduce the level of particles reaching the GT. Today, it is not uncommon for EPA / HEPA levels of filtration to be specified, with particle efficiencies of greater than 85% at 0.2 µm (~95% at 0.4 µm) particle diameters.

As a comparison, the efficiency of a typical air filter for a "previous generation" GT would be ~30% at 0.4 µm, which is an order of magnitude less efficient.

Liquid Removal Capability

The high combustion temperatures of modern GT's have put their turbine components into prime conditions for hot corrosion. The prime cause of this being from Sodium, which most often enters through the air inlet system as a wet, droplet or dry, particle of Sodium Chloride.

The effectiveness of the filtration system against such wet contaminants is therefore an important factor, particularly for modern engines.

Gas and Vapour Removal Capability

With the increased stress levels within modern GT blades, even corrosion of the cold section must now be minimised. Corrosion here is mainly caused by Sulphur and Chloride compounds which often enter the GT inlet in vapour phase. Unfortunately today there is no practical solution available for removing vapour phase contaminants, which is leading to re-design of these GT components, or coatings to make the blades more resilient.

The trend towards increased filtration performance has a secondary effect, one of an increased requirement for maintenance of the filter house and the inlet system itself. This is to maintain seals and joints etc. to support the increased levels of filtration. Also increases in filtration efficiency impact the life of the filters which can lead to earlier replacement of filters and increased GT downtime to do so.

GT Component life – Extended time between Outages

Through the continuous development of GT components and incorporation of lessons learned, the expected service life of critical components has steadily increased over time, leading to longer periods between major outages. This has led to a desire for the inlet filter system components to also have a longer life, such that change out is only required during a scheduled shutdown for other critical component replacement.

This has led to the use of multi stage filter systems which enable the on-line change of pre-filters in between GT scheduled outages.

Fuel Quality – Levels of Sulphur

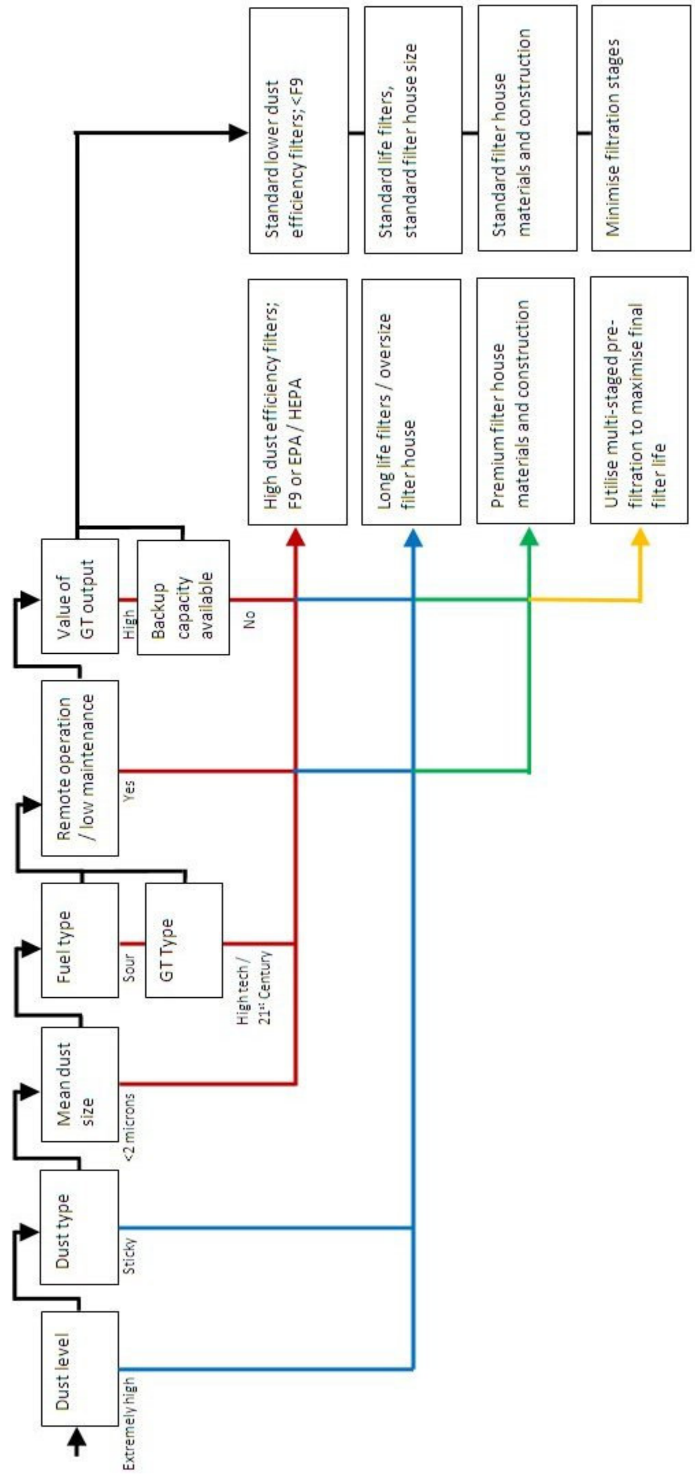
Many of the world's GT's are utilized in the Energy and Oil and Gas industry. The majority of previous GT installations of this type have been either located in developed countries, or near large high quality oil and gas fields, where the fuel available to run the GT is most often "sweet" containing relatively low levels of Sulphur.

In recent years, the need for new power plants has shifted to developing world countries and new oil and gas production has moved to more marginal and lower quality fields. Both of these can often have fuel supplies that are "sour" containing high levels of Sulphur.

As already mentioned, Sulphur in the fuel can mix with Sodium from the air inlet to form rapid corrosion in the hot section of the GT. If the levels of Sulphur have increased in the fuel, it follows that to maintain a similar acceptable level of corrosion to that experienced with "sweet" fuel, the levels of Sodium reaching the hot sections of the GT must be further reduced beyond current levels.

Particulate and Droplet Salt Removal Efficiency

One of the major sources of Sodium in the inlet air is from sea salt. This aerosol is most often abundant in the size range of 2 µm and below, with a large portion below 1 µm in size. This can be in droplet or particulate form, so to further reduce the levels of Sodium reaching the GT, a filter system with increased particulate and droplet removal capability below 1 µm in size is required.



Remote operation – Availability for Maintenance

The demand for new GT installations in; developing countries and more remote locations, where the workforce is less skilled and lacking in GT experience, along with less reliable transportation infrastructure, has led to the need for greater plant autonomy, with reduced maintenance requirements and greater time between outages.

Filter Life

For the filtration system this means yet another challenging requirement for extended filter life, while maintaining a high level of efficiency to maintain GT component life.

ECONOMIC CONSIDERATIONS WHEN SELECTING THE MOST APPROPRIATE FILTRATION SYSTEM

The type and performance of the filter system that is installed on a GT application ultimately becomes a commercial decision. Generally the commercial aspects are considered from two different perspectives and most often as one or the other but rarely both. These are; initial installation cost vs. long term through lifetime cost of the plant.

Initial Installation Cost

Attaining low initial installation costs requires a filter system that:-

- Contains as few filters as possible, so short life.
- As few filtration stages as possible resulting in more frequent changes of the final filters.
- A small filter house so short filter life.
- A filter house manufactured from low cost materials utilizing minimal labour costs, which will require more long term maintenance.

Total Application Through Life Cycle Cost

Unfortunately, to obtain the lowest long term, through life cost often requires the direct opposite of to the requirements for low initial installation cost:-

- Larger number of filters means greater filter life, so longer GT running between filter changes
- Multiple filtration stages to maximise GT component life, as explained earlier, leads to less GT downtime.
- Larger filter house to contain more filters and more stages
- Filter house manufactured from corrosion resistant materials such as stainless steel to reduce the need for through life maintenance and downtime to carry it out.
- Manufactured to a high level of quality to reduce leaks etc. that can lead to a bypass of the filtration. This results in lower through life maintenance.

The consideration of these two aspects of costs is often driven by the particular application of the GT and the value of its output, i.e. the real cost of downtime of the GT to the owner.

Two examples of the extremes of each of these would be; power generation and liquefied natural gas (LNG). When a power generation GT is offline, the loss to the owner of this downtime, is the revenue that would have been earned from the electrical output of the GT, i.e. the $ per MWh. This is often in the range of $10,000s per day for a given GT.

In contrast, when an LNG GT is offline, the value of the lost LNG can often be in the range of $1,000,000's per day. Considering this, it is easy to see why the initial filter system cost may be more important to the power generation application, compared to the total application through life costs most likely to be considered by the LNG application. For this type of application, the avoidance of one day's downtime is likely to more than pay for any additional initial costs to achieve it.

STRATEGY FOR SPECIFYING THE OPTIMUM FILTER PERFORMANCE TO BE USED WITHIN THE PRE-SELECTED MAJOR FILTRATION SYSTEM TYPE

Once the more detailed aspects of the specific GT application, explained in the above sections, are fully understood, the flow chart below can be used to optimize the performance criteria of the specific filter elements to be used within the already selected "major filtration system type".

CONCLUSIONS

The selection of an appropriate and optimised filtration system for a GT inlet system, requires the consideration of many different and often opposing parameters. These include not only the environmental characteristics of the particular location for the GT, but also the specific type of GT being installed, the type of application that the GT is being used for, and even the quality of the fuel being supplied to the GT.

Following the guidelines presented within this paper will enable a good first pass at selecting an optimised filtration solution to overcome the challenges and contradictions that apply to the filter system of a modern GT application.

Gone are the days of a "one fits all" solution for GT inlet air filtration.

REFERENCES

[1] McGuigan, P.T. 2004, "Salt in the Marine Environment and the Creation of a Standard Input for Gas Turbine Air Intake Filtration Systems", ASME Paper GT2004-53113

[2] Brake, C., 2007, "Identifying Areas Prone to Dusty Winds for Gas Turbine Inlet Specification", ASME Paper GT2007-27820

[3] Oswald, A.D., Hiner, S.D., 2006, "More efficient applications for Naval Gas Turbines – Addressing the mismatch between available technology and the requirements of modern naval gas turbine inlets", ASME Paper GT2006-90305

[4] Hiner, S.D., 2000, "Air Filtration Requirements For Gas Turbine Powered Fast Ferries - The Theory And Reality", 16th Fast Ferry International Conference

[5] Loud, R.L., Slaterpryce, A.A., "Gas Turbine Inlet Air Treatment", General Electric & Company

[6] Hill, D.G.T., 1973, "Gas Turbine Intake Systems in Unusual Environments", ASME Paper 73-GT-38

[7] Shelton, L.V., Carleton, R.S., 1984, "The Marine Environment and Its Influence on Inlet System Design", ASME Paper 84-GT-137

[8] Cleaver, R.E., 1990, "Gas Turbine Air Filtration in Tropical Environments", Turbomachinery Maintenance Congress

[9] Cleaver, R.E., 1988, "Retrofitting of Gas Turbine Air Filtration Systems Using Improved Technology", Turbomachinery Two Day Seminar, Paper A1

[10] 1999, "Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size", Ashrae Standard 52.2-1999

[11] 2002, "Particulate Air Filters for General Ventilation – Determination of the Filtration Performance", International Standard BS EN ISO 779:2002

[12] 2009, "High efficiency air filters (EPA, HEPA and ULPA) Classification, performance testing and marking", European standard BS EN 1822-1:2009