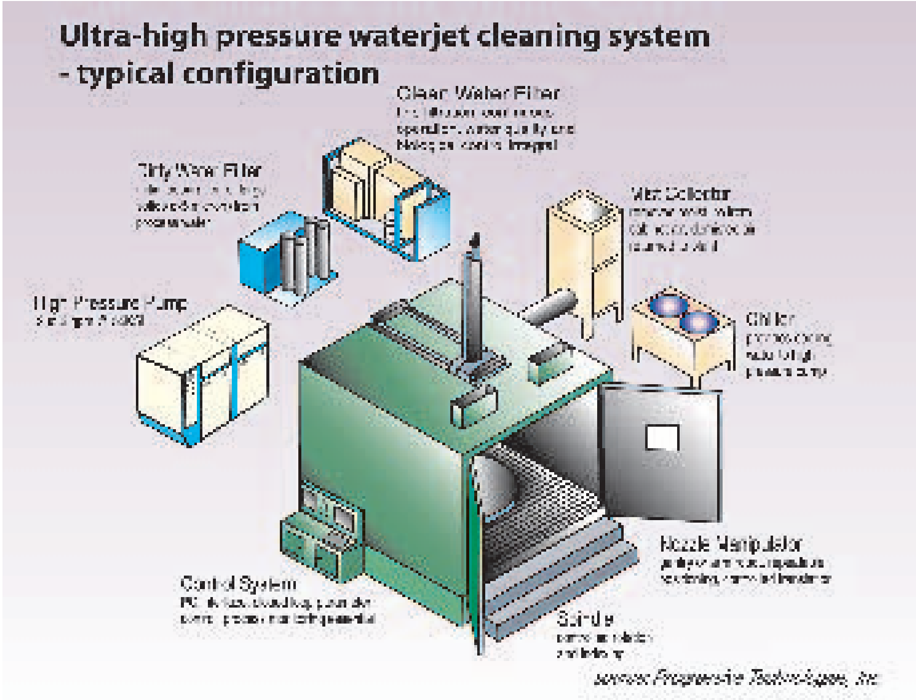
Working under pressure

Jim Whalen of Progressive Technologies discusses why ultra high pressure cleaning technology has found favour in the aero-engine overhaul fraternity, and where its characteristics and economics make it superior as compared with conventional processes.



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Today's aircraft engines employ many different advanced technologies to enhance performance and reduce the costs of ownership. Often, this presents challenges to the organisations responsible for maintenance and overhaul. One example of this is the removal and reapplication of high technology coatings. These may have been applied to improve fan and compressor efficiencies, to reduce surface fretting or to provide a thermal barrier that improves the high temperature capabilities of combustors and turbine components.

Many repair processes require the coatings to be removed for base material inspection, restoration and coating replacement. The task of removing these coatings is quite challenging and, traditionally, mechanical and chemical methods have been used. Mechanical methods usually involve machining, grinding or pneumatic abrasive blasting. Although such methods are fairly efficient in material removal, they tend to lower the life cycle of the component as they often remove parent material along with the coating. Chemical methods are more precise in removing only the coating but these techniques are usually very slow and can produce hazardous waste that is difficult and expensive to dispose of.

Progressive Technologies of Grand Rapids, Michigan, specialises in the production of ultra-high pressure (UHP) waterjet cleaning equipment for the aerospace industry (UHP commonly refers to pressures above 25,000 psi). The company also builds robotic thermal spray coating equipment, pneumatic abrasive blast cleaning and shot peening systems. This combined experience significantly enhances the functionality, robustness and level of process control found in UHP waterjet cleaning equipment.

Technology background

The heart of any UHP waterjet cleaning machine, the intensifier pump, was invented and first used in the industrial environment during the early 1970s. Wood processing and furniture manufacturers utilised the waterjet process to debark trees and to cut complex shapes in fibreboard. As a result of these early practices, many other applications of the UHP waterjet cutting process were developed. Paper products, plastics, and even food have since been processed using waterjet technology.

The mid-1980s witnessed the introduction of abrasive additives into the high-pressure waterjet stream. This new process, called abrasive waterjet cutting, was subsequently used to cut hard materials such as steel, super alloys, composites and stone. It also significantly increased the demand for waterjet technology which has since become widely used and accepted in manufacturing processes. It was not until the late 1980s that the potential benefits of using UHP waterjet cleaning technology were realised. As demand to remove thermal sprayed coatings from aircraft engine components increased, the cost of installing and operating a UHP waterjet cleaning facility became easier to justify.

Process and equipment

UHP waterjet cleaning equipment used to remove thermal sprayed coatings is complex and capital intensive. Systems range in price from $400,000 to over $1,000,000. In general, a UHP waterjet cleaning system consists of five major sub-systems

1) Intensifier pump
2) Waterjet nozzle and drive
3) Process cabinet
4) Nozzle/part manipulator
5) Waste removal and water filtration

The intensifier pump produces between one to three gallons of water per minute (3.8 to 11.4 litres/min) at pressures up to 55,000 psi (370Mpa). The water is delivered to the waterjet nozzle via stainless steel high-pressure tubing or a special flexible hose. There are many different configurations of waterjet nozzles depending on the coating to be removed and the geometric access limitations of the component.

There are two basic types of nozzles used to remove coatings from aero-engine components - the round jet and fan jet. Round jet nozzles create a coherent focused stream of water of between 0.005'' to 0.012'' (0.13 to 0.3mm) diameter. Round jet nozzles are most effective on soft coatings such as rubber, insulation and abradable linings. These soft coatings spall off the substrate when the round waterjet pierces the coating and disperses at the bond line between the coating and the substrate, peeling the coating from the part.

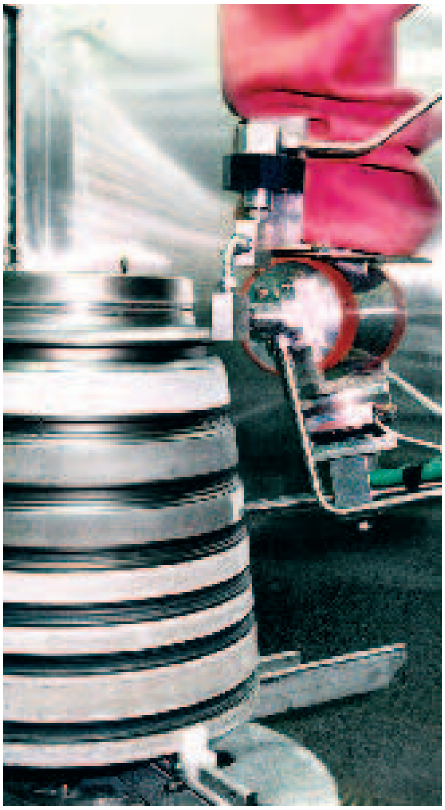
Fan jet nozzles, in contrast, are larger in size, 0.014'' to 0.024'' (0.35 to 0.61 mm) in diameter. The fan jet disperses the water stream into a fan shaped pattern. Fan jet nozzles are very effective on hard coatings that need to be eroded from the substrate rather than peeled from the surface. The fan jet creates a uniform wide pattern of high velocity water droplets that hammer the coating, eroding it from the base material. Typically, both round and fan jet nozzles are rotated at speeds of between 500 to 1500rpm to help spread the nozzle's energy evenly over the work piece being cleaned.

There are several different techniques for nozzle movement. Typically, articulated or gantry robots are utilised to move the rotating waterjet nozzle over the work piece. Uniform, controlled nozzle positioning is critical to controlling the UHP waterjet process. Nozzle angle and traverse speed over the work piece are very important in assuring that coatings are removed and that the base metal is left intact.

Processing components in a UHP waterjet system produces a work environment that is hot, noisy and high in humidity. However, process cabinets can efficiently contain and reduce these effects to acceptable levels. A mist extractor removes mist and humidity and the cabinet interior can be designed to absorb most of the acoustic energy. With the correct engineering approach, UHP waterjet systems can easily be integrated into any manufacturing factory environment.

The final component of a waterjet cleaning system is the water filtration system. This system is critical to the performance of the process since it not only removes the solid waste created, but it also controls the quality of the inlet water to the pump. Most UHP waterjet cleaning systems produce no water discharge and therefore, no waste water is created.

The dirty water filter has replaceable filter media to remove large coating particles from the process water. Typically, several levels of filtration are used to remove coating particles down to 3 microns in diameter. The water is then passed through the clean water filter that further cleans the water down to 0.2



microns which controls biological growth and the accumulation of dissolved metals. The water is then stored for use by the UHP intensifier pump. It should be noted that poor water quality from the filtration system leads to premature wear of intensifier seals and waterjet nozzles, thereby increasing operating costs.

Benefits

For years, the removal of thermal sprayed coatings from aero-engine components has been a very difficult and costly task for overhaul and maintenance facilities. Traditional repair techniques have been partially responsible for increasing turn times and, in some instances, increasing component scrap rates . However, the use of the UHP waterjet cleaning process has greatly simplified the task of removing thermal sprayed coatings and have realised the following benefits:

- The selective removal of coatings without the removal of base metal
- Faster coating removal rates as compared with the chemical removal processes
- Less occurrences of base metal removal as compared with conventional mechanical removal methods (turning, grinding, abrasive blast cleaning)
- Environmental friendliness

Most waterjet cleaning systems can be cost justified simply because of their productivity gains as compared with chemical or mechanical removal processes. The additional benefits of reducing base material damage can result in significant savings as a result of reducing the purchase of new parts. The environmental friendliness of the process is also a benefit that is of increasing importance as disposal regulations and workplace environment rules become more demanding.

Limitations

All manufacturing processes have limitations. The most significant limitation of UHP waterjet cleaning is related to cost. As previously mentioned, these systems are complex and very capital intensive, with starting prices in the region of $400,000. In addition to the capital costs, UHP waterjet equipment has moderate to high operating costs. Although influenced by the process application and use, waterjet systems will cost $20 to $40 per pump hour to operate, inclusive of energy and consumable parts.

UHP waterjet cleaning systems also have limitations with regard to the types of coatings that can be removed. It is not practical to use the UHP waterjet process to remove coatings that have been applied with the high velocity oxygen fuel (HVOF) thermal spray process or brazed honeycomb. Even with these limitations, many users have justified the use of the UHP waterjet process over mechanical or chemical removal methods. Most see a return on their capital investment within nine to 12 months after system installation.

Common applications

The first application of UHP waterjet cleaning was the removal of thermal barrier coatings from aero-engine combustors. These coatings consist of a ceramic topcoat with an oxidation resistance metallic bond coat.

Traditionally, this coating required abrasive grit blasting to remove the ceramic topcoat and a chemical bath to remove the metallic bond coat - a very time consuming and expensive process.

Today, the UHP waterjet process has broad application across all modules of aero-engines. Abradable coatings are frequently removed from fan and compressor cases at engine overhaul.

Whilst these coatings are relatively soft, they are difficult to remove mechanically. The UHP waterjet process removes them very quickly, improving productivity and reducing part damage as compared with competing mechanical machining or scraping methods.

Combustors can be cleaned with the waterjet process. This remains the most difficult UHP waterjet cleaning application since the combustor's high operating temperatures cause the metallic bond coat to diffuse into the base material, making it very difficult to remove. The competing chemical process is time consuming and with the introduction of more stringent environmental regulations, the resulting costs of chemical stripping become prohibitive.

Another challenging application is the removal of wear or restorative coatings.

Coatings such as tungsten carbide, chrome carbide, nickel aluminide, and inconel are commonly used to protect components from wear, or to restore a worn features. Wear resistant coatings are hard and require aggressive UHP waterjet cleaning, nozzle and work piece velocity control is critical to ensure base metal protection. Restorative coatings are also relatively hard but are often thicker. Nevertheless, aggressive parameter settings are also required to effectively remove these coatings.

The final class of engine components processed are rotating parts. The number of applications that process compressor rotors, rotating seals and shafts is increasing. Wear coating on seal teeth, and abradable coatings of stator rub lands are now being removed with the waterjet process.

Future advancements

UHP waterjet cleaning has become a mature process over the last decade. It is a process that continues to receive quite a lot of research and development funding from the equipment suppliers and even the end users. Advances will be made in equipment component design to reduce maintenance costs. Also, process research will evaluate the benefits of even higher water pressure (above 60,000 psi, 410 Mpa), possibly increasing the cleaning rate or reducing the detrimental effects on base materials. As aero-engine component designs become more complex, waterjet application engineers will continue to develop smaller, innovative nozzles to remove coatings from confined areas. Equipment manufacturers will also begin to design and build smaller compact UHP waterjet cleaning cells with a lower cost of ownership. In general, technology will continue to advance towards lower capital and operating costs while new methods of process application will be developed for a wider array of components. ●