

High Pressure Water Stripping Using Multi-Orifice Nozzles

David Hoppe
NASA/MSFC
Mailstop: EH33
Huntsville, AL 35812
(256) 544-8836

Abstract

The use of multi-orifice rotary nozzles greatly increases the speed and stripping effectiveness of high pressure water blasting systems, but also greatly increases the complexity of selecting and optimizing the operating parameters. The rotational speed of the nozzle must be coupled with its transverse velocity as it passes across the surface of the substrate being stripped. The radial and angular positions of each orifice must be included in the analysis of the nozzle configuration. Orifices at the outer edge of the nozzle head move at a faster rate than the orifices located near the center. The energy transmitted to the surface from the impact force of the water stream from an outer orifice is therefore spread over a larger area than energy from an inner orifice. Utilizing a larger diameter orifice in the outer radial positions increases the total energy transmitted from the outer orifice to compensate for the wider distribution of energy. The total flow rate from the combination of all orifices must be monitored and should be kept below the pump capacity while choosing orifice to insert in each position. The energy distribution from the orifice pattern is further complicated since the rotary path of all the orifices in the nozzle head pass through the center section. All orifices contribute to the stripping in the center of the path while only the outer most orifice contributes to the stripping at the edge of the nozzle. Additional orifices contribute to the stripping from the outer edge toward the center section. With all these parameters to configure and each parameter change affecting the others, a computer model was developed to track and coordinate these parameters. The computer simulation graphically indicates the cumulative affect from each parameter selected. The result from the proper choices in parameters is a well designed, highly efficient stripping system. A poorly chosen set of parameters will cause the nozzle to strip aggressively in some areas while leaving the coating untouched in adjacent sections. The high pressure water stripping system can be set to extremely aggressive conditions allowing stripping of hard to remove adhesives, paint systems, and even cladding and chromate conversion coatings. The energy force can also be reduced to strip coatings from thin aluminum substrates without causing any damage or deterioration to the substrate's surface. High pressure water stripping of aerospace components has thus proven to be an efficient and cost effective method for cleaning and removing coatings.

Standard Operational Parameters Effects

There are several basic operating parameters which determine the stripping effectiveness for any high pressure water blast system. The pressure and the flow rate determine the energy potential available for removing coatings. The quantity and combination of orifice size affects the pressure and flow rate. The orifice configuration must be calculated to ensure that full pressure is available at the pump run out point.

The type and design of the orifices are also an important consideration. The energy potential of the water stream is reduced as it passes through the restriction of the orifice. This reduction is dependent upon the nozzle material and the internal structural design of the flow path. The selection of different orifice designs and different materials can give a wide range of efficiencies. Material type must also be taken into consideration to allow the restriction to be strong enough to prevent excessive wearing. A quickly wearing orifice will change the flow characteristics of the nozzle and reduce the maximum pressure obtainable.

At high operating pressures, water velocities are above the sonic level. The water emerges from the nozzle as a very coherent unidirectional stream. As the stream passes through the air, the water molecules interact with the air and cause turbulence to be introduced into the outer layer of the stream. As the water stream continues to interact with the air, more of the water molecules break away from the solid cohesive flow until the solid core of the water stream no longer exists. As the water flow becomes turbulent its motion becomes more random and the velocity slows down the longer it interacts with the air. This causes the energy potential of the water stream to be reduced the further away the water has traveled from the exit of the orifice until the water streams are just a mist.

The distance between the nozzle exit and the substrate (stand-off distance) is therefore another critical parameter which must be carefully selected. If the exit of the nozzle's orifice is too close to the surface of the object to be stripped, the water stream impacts the surface as an extremely cohesive stream basically, the diameter of the exit of the orifice. This results in a very aggressive stripping at the point of impact but only a fine line of coating removed as the water stream passes across the surface. If the exit of the nozzle's orifice is too far from the surface of the object being stripped, the water stream has dispersed into a wide random mist and lacks sufficient energy to remove most tightly adhering coatings. With a properly selected standoff distance, the water stream maintains enough of its coherent flow to transfer sufficient energy to the surface of the substrate while having sufficient interaction with the air to cause just enough turbulence to expand the width of the stream into a larger impact area without greatly reducing the energy potential of the water stream. This optimized standoff distance allows the water stream to strip a path across the substrate wider than the diameter of the orifice.

When a coating is removed by the mechanical impact of water striking the surface, the coating travels away from the impact point dependent upon the characteristics of the

coating. A thick coating with poor adhesion quality but strong tensile strength will more than likely fly off the substrate in large chunks. As the water stream cuts through the coating and impacts the hard substrate underneath, the water velocity vector changes tangentially to the substrate, slicing through the bond between the coating and the substrate and dissipating the rest of its energy as it recoils from the surface trying to cut back through the coating. The water then is able to penetrate the coating, cut tangentially through the bond surface for a short distance and randomly dissipate back through the coating cutting and lifting off a large piece of the coating around the area of impact. A stream running perpendicular to the surface will give a somewhat symmetrical stripping of the coating following the path of water impact. An angled water stream attack will skew the removal of the coating in the direction of the attack angle. Since the water stream no longer is required to make a perpendicular change in direction, but will mostly turn in the direction of the angle of attack, less energy is lost during the direction change. This allows more energy to be available to dissipate into the coating as it cuts through the bond line and back up through the coating. The result is a larger amount of coating removed than from a perpendicular impact.

For thin, tightly adhering coatings, there is no sympathetic stripping as can happen with the thicker less tightly adhering coatings. The area of removal of the coating is basically the same as the area of impact of the water stream. The coating then is reduced to extremely small bits as if it were dissolved in the water. The angle of attack then is not of any great consideration.

In the case of soft, tacky coatings, such as thick grease, the removed material could reattach itself after the water stream moves away from its impact position, loses energy and slows down. The water stream again cuts through the coating but as it makes its directional change, it pushes the coating away from the point of impact rather than cutting through a bond line. As the water slows, it loses energy allowing the bonding strength of the material to reattach to the surface of the substrate in a different location. Skewing the direction of water flow after its impact by adjusting the angle of attack will aid in the removal of the coating by pushing most of the coating in one direction. By adjusting the next pass across the surface to be in the same direction of the angle of attack, the coating can be essentially washed toward the edge and pushed off the surface. Gravity also plays a small role resulting in a downward angle aiding in the removal of this type of coating.

The water stream must be kept moving across the surface at all times. Prolonged dwelling of the water at any one spot will cause damage to the substrate. Even low pressure, low flow rates that dwell in the same location will eventually erode the hardest materials. The faster the stream passes across the surface, the quicker an area can be covered during stripping. The quicker the area covered during stripping, the wider the area over which the energy is spread. The wider the area over which the energy is spread, the lower the capability the system has to strip. The transverse velocity must therefore be optimized to balance moving as quickly as possible to cover the largest area possible in the shortest amount of time while moving slowly enough to ensure that the water stream removes the coating.

Two other factors can be selected to help in the balancing of the transverse velocity. The water stream can be set to overlap the previous stripping pass by a certain amount or the exact same path can be repeated multiple times. Since the outer part of the water stream breaks up and loses energy to the air it passes through while the center core may remain mostly intact all the way to the surface, the center of the impact receives more energy than the outer edges of the impact area. This invariably results in a well-stripped center section with tapering of the coating removal toward the edges of the strip path. By selecting an overlap such that the tapered edge of the next pass across the surface coincides with the opposite tapered edge of the previous pass, the energy imparted to the surface from the combination of two outer reduced energy areas can be sufficient to match the energy in the center of the strip path and therefore fully strip the coating evenly. The overlap can be adjusted as determined to be most effective. At a 50% overlap, the outer edge of the nozzle, passes across the center of the stripped path of the previous pass and the center core of water will pass over the outer edge.

Some times it is necessary to slow the transverse velocity to a small value in order to ensure that complete stripping of the surface occurs in one pass. This can result in slower than necessary stripping rates. Faster stripping rates may be possible by speeding the transverse velocity while planning to pass over the entire surface more than once. A double impact to a coating can be more efficient than one single blow. A coating to be removed must be tested to determine the transverse velocity necessary to fully remove the coating in one pass compared to stripping the coating in two or more passes. If the transverse velocity can be more than double using a two pass method, quicker stripping times will be achieved than with a single pass over the surface. When using double pass stripping parameters, it may be best to stagger the starting position of the water stream by at least half the difference between the stripping width less the amount of overlap. This keeps the most energetic part of the water stream from passing over the exact same spots on the substrate giving a better distribution of energy over the entire surface. For hard to remove coatings, operating with a 50% overlap between passes across the surface will cause the least energetic part of the water stream to pass over the path of the previous path's most energetic part of the water stream.

The effects from utilizing double passes can be combined with the overlap parameter by moving the nozzle only half of the nozzle strip width between passes. This would be identical to the 50 % overlap process. This not only causes the outer edge of the nozzle to pass across the center of the strip path on succeeding passes, but also results in water streams covering the substrate twice in a single run.

Some nozzles are designed to mix abrasive materials with the water stream. Abrasive material can increase the stripping capability of a high pressure water stream by several orders of magnitude. Care must be taken when operating under these conditions since this more energetic stream can quickly start cutting into the substrate. With all the different types of abrasives available, a type to suit each purpose can be selected. Crushed walnut shells are soft enough to minimize the danger of cutting into substrates

while garnet can be sufficiently aggressive to cut through several inches of hardened steel. Most nozzles designed for the mixing of abrasives use the vacuum from a venturi to pull the media into a mixing chamber and a second focusing nozzle to control the stream at the outlet. While greatly speeding up the stripping process, the use of solid additives to the water stream will add a large amount of material which must be cleaned up and disposed of after completion of the stripping process.

Special Operational Parameters Effects for Multi-Orifice Rotary Nozzles

Using multi-orifice rotary nozzles greatly complicates the choosing of operational parameters. With multi-orifice nozzles, the number of orifices, their positions within the nozzle head and the size of each orifice must be selected. The rotational speed of the head must be matched to the transverse velocity. Changes in the angle of attack give different stand-off distances between each orifice and the substrate at different times. The total tangential velocity of each nozzle will be different and variable as the head spins. The overlap between passes is more complex due to the different tangential velocities and the combination effect caused by more than one orifice passing across certain sections of the substrate.

The first consideration in choosing the orifices to be placed in the rotary nozzle head is to determine the inside diameter of each orifice. The total flow rate from all the orifices selected must not exceed the capacity of the pump at its rated pressure. If orifices are chosen which allow a larger flow rate than the pump is capable of delivering at its rated pressure, the system will operate at a lower pressure than normally achieved at the pump's rated flow rate. Different operating pressure and flow rate combinations can be chosen in this way. Operating the pump at its maximum flow rate and pressure will provide the maximum potential energy for stripping. Operating a positive displacement pump at its rated pressure, but at a reduced flow, can cause excessive heating of the pump. The pump still adds energy to the water by increasing the pressure, but the flow is lower which reduces the amount of water passing through the pump for cooling. The size and combination of the different orifice sizes must be selected to spread the energy distribution from the orifices evenly over the area to be stripped. The total speed of each orifice is a combination of the transverse velocity of the head moving across the substrate and the tangential velocity from the rotation of the head. Since each orifice is located on a different radius for many nozzle heads, the speed of each orifice will be different. The rotation of the head causes the orifice's tangential velocity from the rotating head to be in the same direction of the transverse velocity some times and in the opposite direction at other times, the total velocity of each orifice will change sinusoidally with a magnitude equal to twice the transverse velocity as the nozzle head rotates and moves across the surface. If the nozzle moves in the same direction on the next pass across the surface directly below the previous path with a small overlap, the faster orifice speeds will overlap the areas with the slower speeds. If the next pass is in the opposite direction, the tangential component of the orifice velocity will cause the slower speeds to overlap the same lower speeds and the faster speeds to overlap the same faster speeds at successive

passes. If the tangential component of the velocity vector is much greater than the transverse velocity component the difference between the velocity of the orifice while the head moves one direction may be close enough to the velocity of the orifice when the head moves in the opposite direction to minimize this effect so that it need not even be considered. The velocity components should be checked before making this assumption.

The spray pattern across the surface of the substrate from multi-orifice rotary heads is trigonometrically dependent upon the transverse velocity, rotational velocity of the head, radial location of the orifice, and the angular location of the orifice in relation to other orifices. Since the orifice are fixed on the nozzle head, the only two operational parameters which can be modified are the rotational velocity and the transverse velocity. These parameters must be chosen to complement each other in order to spread the spray pattern evenly across the substrate. (See figure 1) All orifice move perpendicular to the transverse direction through the center section of the substrate. A high transverse velocity can spread those perpendicular paths far apart making it impossible to evenly cover the surface. The wrong combination of rotational and transverse velocities can cause individual orifice to spray directly at the same exact position that other orifice spray through the center section while leaving adjacent sections of the substrates with gaps where no spray comes in direct contact. This results in areas where too much energy has been applied to the surface causing the removal of underlying coatings which were not meant to be removed or damage to the substrate itself while leaving the adjacent areas with the coating intact and untouched. (See figure 2)

Since the tangential velocity of a rotating object increases proportionally with the radius, the orifice in the outer areas of the rotary head will move at a much quick speed than the orifices located nearer the center of the head. Water jets from orifice moving at a quicker pace will spread the potential energy of the water stream over a larger area than orifice moving slower. This causes an imbalance in the stripping ability of the nozzle from the outer areas across the center of the nozzle. In order to compensate for the difference in potential energy imparted to the substrate per linear inch of orifice travel, larger orifices are placed in the outer locations with incrementally smaller orifice diameters placed in subsequently closer locations to the center of the head. The force that the water exerts across the surface is inversely proportional to the square of the total velocity of the orifice. These calculations must be taken and included when specifying the size of orifice to be placed in each location of the rotary head. To further complicate the selection of orifice size and locations, every orifice on the head will pass through the center area of the nozzle path while only the outer most orifice will pass across the outside edge of the path. The energy imparted to the center of the nozzle path will be a combination of the energy imparted from the passes of all the orifices while the energy imparted to the substrate at the edges is due only to the one orifice at the extreme edge of the nozzle head. This is further complicated but at the same time minimized, by the direction the water stream travels over the surface at these two locations. The water stream at the radius of each orifice from the transverse motion path moves in the direction or opposite to the direction of the transverse velocity while the water stream at the center of the nozzle path moves perpendicular to the transverse direction. This causes the water stream at the

radius to cover a small strip along the path of the transverse velocity. The water streams at the center then cut a line perpendicular to the transverse velocity and with the correct combination of rotational speed and transverse velocity, each orifice will pass over a separate section of the substrate minimizing the number of multiple hits each spot on the substrate receives.

The wider the nozzle head, the more severe is the effect of changing the angle of attack. A perpendicular face to the substrate will maintain all orifice an equal distance from the substrate as it passes across the surface. Even nozzle heads with divergent flows from the different orifice will maintain the same stand-off distance as the head rotates. When the nozzle head is canted even a few degrees it causes each orifice to pass closer to the surface as the nozzle head rotates past the point where the nozzle is inclined toward the substrate and to pass further from the substrate 180° around. Since the range of most orifice inserts in these nozzles have a small effective stand-off distance, (between 1 and 3 inches), a small inclination can easily move the orifice outside of its most efficient operating range.

Since the geometry of the orifice is fixed with reference to its radial and axial positions for each orifice, the size and type of each orifice must be tailored designed for optimal stripping. Based on the location of each orifice, the relationship between the rotational velocity of the nozzle head and the transverse velocity can be calculated and graphically shown to determine the effectiveness of the spray pattern coverage. Additional problems setting the operating parameters for optimal stripping can then be smoothed out by selecting a proper overlap parameter.

Conclusion

A proper set of operating parameters will allow for a high pressure water stripping system to operate quickly and cleanly with a high level of efficiency. A failure to understand and select the proper parameters can result in a frustrating system which fails to perform satisfactorily either by allowing gaps in the stripping process or by over stripping and thus causing damage to the substrate. High pressure water stripping systems utilizing multi-jet orifice nozzle heads have been used to strip a wide variety of materials with great success.

Figure 1
Correct set of operating parameters.

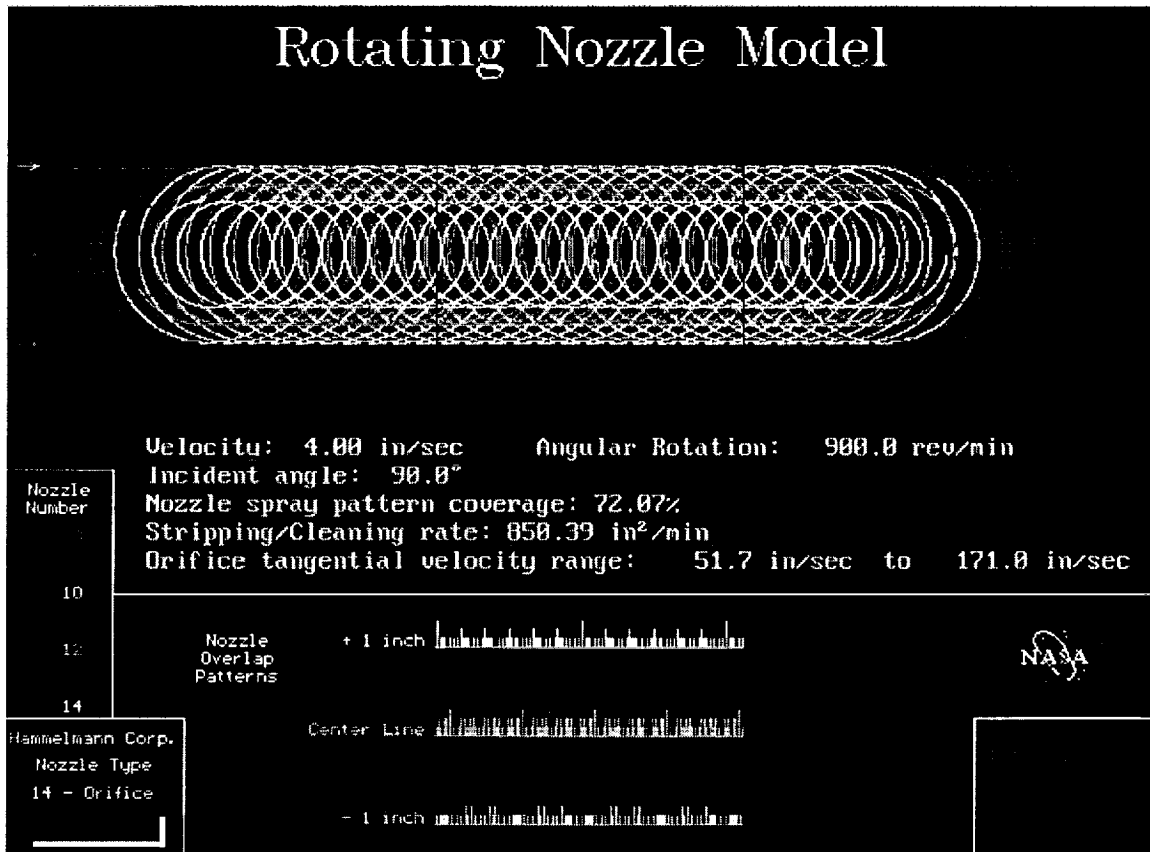


Figure 2
Incorrect set of operating parameters.

