Pipe Cleaner

FMC Technologies cuts the weight of a reciprocating pump for sewer pipe cleaning in half while reducing its footprint and increasing its pressure output. This creates a highly competitive product.

By **Mario Ruvalcaba**,
Pump Product Engineer,
FMC Technologies, Texas, USA

A sewage pipe can become caked with grime and debris after long periods of use, reducing its internal diameter and limiting the volume of waste water it can handle at any time. Following a storm, it may become choked with dirt, rocks, branches, bottles, cans, plastic bags, and other natural and man-made debris. Routine maintenance using high-pressure water jetting is one way to remove the buildup and keep the pipes open for proper operation.

Trucks containing a large water tank and a high-pressure pump are often used to combat the clogging of sewage lines. In general, sewer pump pressures range from 2,000 psi to 4,000 psi. Lower pressure with high flow is used in larger sewer pipes, while high pressure with low flow is used for smaller pipes. High pressure (4,000 psi) is best used for removing root infiltration, because water at that pressure can cut the roots out of the pipe.

FMC Technologies designs and manufactures reciprocating pumps for this application. In recent years, the customers have been demanding smaller and lighter pumps so operators don't have to carry heavy equipment in the field. Reducing size and weight also makes pumps less expensive to purchase, easier to maintain and more energy efficient. But high pressures impart greater forces to smaller components, so the crankshaft, plungers, connecting rods, bearings and pump housings have to be stronger than the components of a larger pump.

"The simulation enabled FMC Technologies' engineers to make the reciprocating pump 50 percent lighter."

^ Crankshaft fatigue analysis using ANSYS nCode DesignLife

FMC Technologies' engineers had been using ANSYS solutions successfully for subsea oil drilling rig design, so they decided to use ANSYS Mechanical to optimize the size, weight, strength and lifetime of reciprocating pumps for sewage pipe cleaning without the loss of effective lifetime or pumping efficiency.

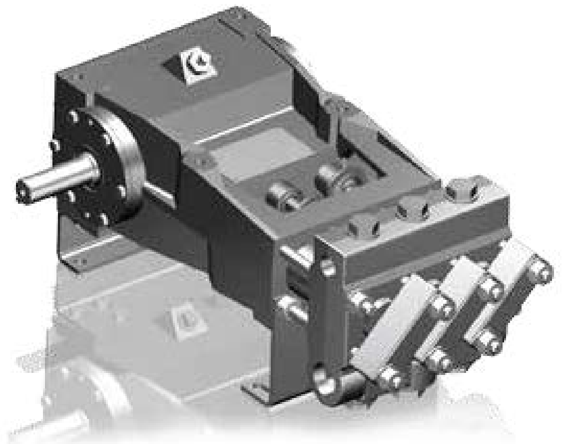
Reciprocating Pump Operation

Reciprocating pumps are part of the family of positive displacement pumps—they displace a fixed amount of volume for every stroke of the crankshaft, and work like a syringe. A plunger moves up and down; when you pull it up, it draws liquid in, and when you push it down, it drives the liquid out. On a reciprocating pump, every time the crank moves down, the plunger moves out and fluid is drawn in through the pump's suction port; when the crankshaft completes a full cycle, it moves up, pushing the plunger forward and the fluid out. The number and size of the plungers determine how many gallons per minute you can pump. In industry, three or five plungers are common. An electric motor or a diesel engine drives the crankshaft and moves the plungers to produce flow.

The discharge end of the pump is pressurized to the desired operating pressure —in this case 4,000 psi — by restricting the downstream flow with a valve or some other pressure control device. The high pressure is necessary to provide enough force to blast away the buildup inside the sewage pipe, but it also puts high stress on the pump's components. The crankshaft, plunger, connector rods, bearings and housing will all experience this high load. Optimal design is needed to ensure that components will not break during operation, thereby maximizing the pump's lifetime.

Simulating a Smaller, Lighter Pump

To design a pump that would be lighter than their standard 245 lb (111 kg) sewage-cleaning pump while increasing the outlet pressure from 3,000 to 4,000 psi, FMC Technologies' engineers modeled the



^ Former model of FMC high-pressure sewer cleaning pump

^ New sewer cleaning pump from FMC after redesign using ANSYS simulation solutions

complete, 25-component pump system, with special emphasis on the crankshaft. The crankshaft was modeled as a cast iron part with flexible structural behavior and approximately 200,000 elements in the mesh; the remaining 24 components — plungers, connector rods, bearings and housing — were modeled as rigid bodies. The model contained multiple contact joints, some of them with fixed behavior and others with one or two degrees of freedom. Each joint had one or two coordinate systems. Applied force and joint rotation were used as boundary conditions. The goal was a robust design in which the highest stresses were significantly below the material yield strength to avoid plastic deformation. Parameters of interest in the results were total deformation, maximum equivalent, maximum principal and shear stresses.

Because of the cyclic rotational nature of the crankshaft's movement, during which the load changes from a maximum to a minimum, engineers performed fatigue analysis using ANSYS nCode DesignLife to ensure a robust design safety factor for fatigue.

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Optimized Designs for Fatigue Using ANSYS nCode DesignLife
ansys.com/fatigue

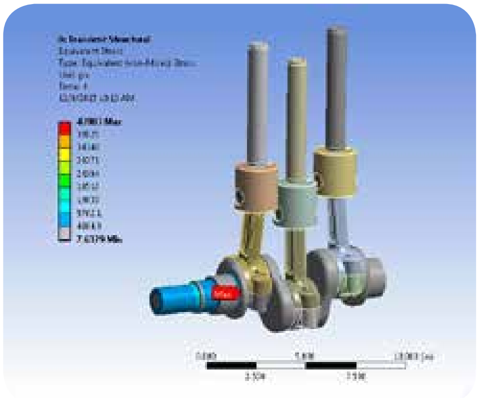
Simulation Challenges

Simulating a complex system with 25 components proved to be challenging. Even though the focus was on the crankshaft, FMC Technologies' engineers could not analyze it by itself because it is linked to all the other components. Furthermore, a crankshaft is a dynamic application: Every time it moves, each component is in a different position at a different angle, so the stresses vary widely. Such a dynamic application requires a dynamic analysis. Consulting with ANSYS support personnel, the team decided to manage this complexity by simulating the movement of the crankshaft through one complete revolution. Analyzing how the plungers moved up and down and how that changed the load on each part resulted in the necessary dynamic analysis.

Even with this strategy in hand, other challenges remained. On the first simulation run, the analysis did not converge as expected. After changing some simulation parameters, including boundary conditions that were overconstraining the model, the analysis did converge, but the calculated stresses were completely out of range — too high to be true, as confirmed by hand calculations.

One complication was the large number of joints linking all the components. Each of these joints has specific degrees of freedom because the components are in motion, and each has its own coordinate system tied to certain phases of the component. Failure to choose the right degrees of freedom for one component can adversely affect variables for the rest of the assembly.

Working with ANSYS support engineers on many simulation iterations over the course of a month and making systematic adjustments to the model based on the results of these iterations, an optimal design solution for the reciprocating pump emerged. Compared to the many months this design would have taken using the old build-and-test method, FMC Technologies saved much time and cost using ANSYS solutions.



^ Stress on pump crankshaft displayed in ANSYS Workbench

A Better, Competitive Pump

The final, nonlinear, transient-structural analysis using ANSYS Mechanical and ANSYS nCode Design Life took 36 continuous hours of simulation time on a 12-core computer. The simulation enabled FMC engineers to make the reciprocating pump 50 percent lighter, reducing the weight from about 245 lbs (111 kg) to approximately 130 lbs (59 kg). The pump's length was shortened by 25 percent, and the pressure was increased from 3,000 psi to 4,000 psi, providing much more blasting power to clean the sewer pipes.

Internally, the forged alloy steel crankshaft of the new pump is 12.75 inches long and only 1.625 inches in diameter. Even at this small diameter, it can withstand the 4,000 psi force for the lifetime of the pump — quite an achievement. The previous pump had two shafts: a pinion shaft that drives a bigger crankshaft with a gear. Producing a single-shaft design greatly helped to reduce the size and weight of the pump.

FMC Technologies can now offer the sewer cleaning industry a lighter, energy-efficient and highly competitive pump. Having analyzed every component with ANSYS engineering simulation tools to ensure that it would be robust, FMC Technologies' engineers can meet the demanding applications of today's sewer cleaning market. Λ