Summary for the final report

Development and validation of a method for the generation of impulse collecting hammer jets for spray cleaning to the bionic model of the archer fish (BionicJet)

Across all industries, wet chemical cleaning processes are the most important and widespread cleaning methods. Spray jet cleaning plays a key role in these processes. As a result of increasing environmental protection requirements and necessary cost reductions, there is a general desire in the food-producing industry for shorter cleaning times and the saving of resources (water, cleaning agents, energy, etc.) during the cleaning process. In spray jet cleaning processes, a reduction in cleaning time can be achieved directly by increasing the mechanical effect of the jet. For this purpose, an increase in pressure or flow rate can be considered, since both variables have a direct influence on the impact force. As a rule, this increase cannot be realized at will, since the maximum adjustable operating pressure of the cleaning system is limited by plant or process technology (usually 2 - 6 bar for spray jet cleaning) and an increase in the volume flow is not practicable in terms of resource efficiency. For this reason, this project looked for another way to increase the mechanical cleaning efficiency while conserving resources.

The basis of the new cleaning approach is the unique and impressive hunting behavior of the archerfish. To increase its hunting success, this fish is able to shoot on insects above the water surface with a precise water jet. It varies the jet velocity so that the front of the jet moves more slowly than the tale of the jet to create a compact drop upon impact. Due to the increase in liquid mass at the jet front, the impact force consequently also increases. Accordingly, a technical implementation of this principle leads to a decrease in cleaning liquid consumption with a simultaneous increase in the cleaning efficiency.

During the project, the requirements for the novel principle were first worked out with the project advisory committee (pbA) and documented in a list of requirements. In addition, a theoretical approach had to be developed to imitate the modulation principle of the archerfish. In addition, test rigs were set up to investigate the fluid mechanics of the jets and to perform jet force measurements and cleaning tests. For this purpose, a laboratory system was set up which generates the necessary velocity modulation by means of a syringe whose piston is driven by a linear motor. The design of this laboratory system was intended to ensure a very high reproducibility of the modulated jets. For this reason, glass nozzles were used to minimize geometry-related influences on the jet surface. Furthermore, the secondary jet breakup could be minimized by the specific adjustment of the PID controler of the linear motor.

For a large parameter range, it could thus be shown that the modulation approach leads to an accumulation of fluid at the jet front. The parameters were the initial and maximum velocity of the jet, the ejection angle (inclination from the horizontal axis) and the distance from the nozzle to the surface. Based on the force measurements, it was also shown that the modulation leads to a significant increase in the maximum impact force, which in some cases is 23 times that of a comparable intermittent jet. The cleaning tests with the contaminants mustard and ketchup also showed a significant increase in the cleaning effect.

To ensure the subsequent usability of the new cleaning approach, the jet modulator of the laboratory system had to be converted into a version suitable for industrial use. To this end, a total of six different concepts for modulation generation were developed within the project (3 each by the two research institutes). In coordination with the pbA, four of these concepts were implemented and their functionality investigated. Based on the data obtained, a utility analysis could then be performed to determine the most suitable solution for industrial use. The underlying evaluation system of this utility analysis is based on the requirements list that was developed with the pbA. The solution with the greatest utility value was achieved by a modulation generator that produces the desired jet modulation with a proportional valve. This solution was then further developed and optimized for a robot application. This allowed a demonstrator to be built that shows the use of the new cleaning approach in an industrial environment. Cleaning tests with 3 food contaminants and a lubricant were used to demonstrate the efficiency of the new approach. A significant 35% reduction in cleaning time was achieved.

In addition, a high-resolution three-dimensional numerical simulation model was built in Basilisk based on the volume-of-fluid methodology. This was validated by the extensive experimental work. By performing impact simulations, it was possible to obtain additional information on the distribution of tangential and normal stresses during drop impact. It was found that the modulation leads locally to partly 100 times normal and 10 times tangential stresses. The simulated integral normal force coincides with the experimental data.

During the project processing, optimization potentials were uncovered which could not be solved within the duration of the project. These include the consideration of an additional nozzle movement and gravity in the modulation approach, which necessitates an additional adjustment of the ejection angle during the ejection process. This is technically challenging because the angle adjustment must occur within a few milliseconds. In addition, a desire arose in pbA to investigate modulation for larger distances and alternative cleaning fluids. The use of surfactants, for example, fundamentally changes the properties of the cleaning fluid. The decisive variables here are viscosity and, above all, surface tension. The latter is decisive for the successful accumulation of liquid at the jet front. A reduction in surface tension, caused by the addition of surfactants or other liquids (ethanol), can therefore have a decisive influence on droplet formation. Further development of the new modulation generator could thus significantly increase the efficiency of the cleaning system and should therefore be pursued without fail.

IVLV members can download the complete final German project report from our homepage. All you need is to register in the section "My IVLV". Non-members can request the final report from the IVLV office at office@ivlv.org .

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