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# A Novel Cutting Technology for Chemical Environments Using Pulsed Abrasive Water Jet

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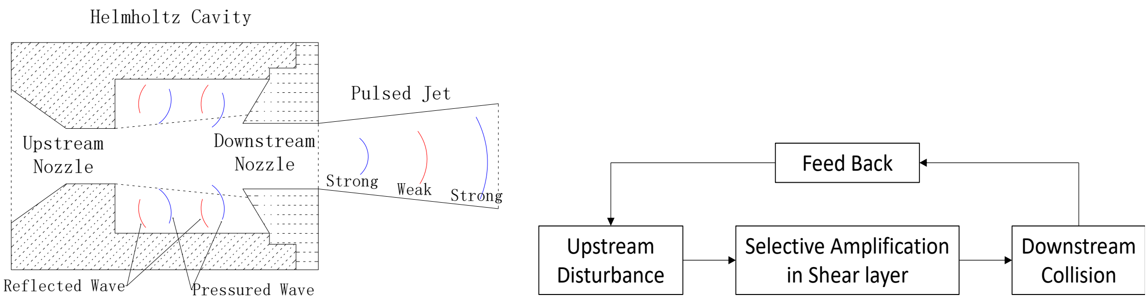
This paper aims to apply the self-excited oscillation pulsed (SEOP) water jet to metal cutting in chemical environments. For this purpose, the impact force of the water jet was compared with that of continuous jet under different flow pressures and at different target distances. The results show that the impact force of pulsed water jet was much greater than that of the continuous jet. After that, some abrasives were introduced to the pulsed water jet to enhance its cutting ability. Following this train of thought, a portable cutting system was assembled and examined in details. It was proved that the portable cutting system was convenient and effective for chemical environments.

## 1. Introduction

The self-excited oscillation pulsed (SEOP) water jet is a discontinuous jet with pulsed impacts. It is developed based on fluid dynamics, hydraulics, resonance and elasticity (Rockwell, 1979 & 1980; Wang, 2014; Liu, 2015; Wang, 2015; Li, 2016). The creation of SEOP water jet relies on two essential elements: selective amplification and disturbances (Dehkhoda, 2013 & 2014; Liu, 2015; Wang, 2015).




(a) (b)

*Figure 1: The creation of SEOP water jet*

As shown in Figure 1(a), the high velocity and instable shear layer is disturbed by surrounding environment after the water flow passes through the upstream nozzle. In this case, the cross section of the jet begins to expand and surpasses the size of the downstream nozzle. When the jet reaches the downstream nozzle, it clashes fiercely into the downstream wall and releases high kinetic energy. The clash is so short-lived that most of the kinetic energy is pushed back as a reflected wave, that is, the feedback in Figure 1(b). The reflected wave greatly weakens the upcoming water flow, leading to a weak water jet during the feedback process. When the reflected wave arrives at the upstream wall, a similar clash happens again. At this time, the pressurized wave speeds up the water flow dramatically. During this period, the water jet becomes strong and

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powerful. The same process runs over and over in the Helmholtz cavity, resulting in a periodic pulsed jet (Mejia, 2015; Shi, 2015).
This paper compares the impact features of the pusled water jet with those of continuous jet at different flow pressures and target distances, and develops an SEOP-based portable cutting system according to the features of chemical environments.

## 2. Experiment

### 2.1 Experimental system and plan

The experimental system (Figure 2) consists of such three parts as the power module, the nozzle module, and the data acquisition module. The power module has a 250L water tank providing stable water flow and a plunger pump with maximum output pressure of 40MPa and flow rate of 40L/min. The nozzle module, as the centrepiece of the experimental system, employs both self-excited oscillation nozzle and conventional continuous jet nozzle. The diameter of the former is 0.8mm in the upstream, and 1.2mm in the downstream; the diameter of the latter is always 0.8mm. The data acquisition module contains a quartz piezoelectric force transducer (range: 5kN; sensitivity: 3.79pC/N) and an AMSY-6 high-speed data acquisition device (Vallen). The device, essentially an acoustic emission monitoring system, can adapt to the selected force transducer and provide enough sampling frequency. The pre-amplifier of the device is a broadband amplifier. In addition to covering all needed frequency bands, the pre-amplifier does well in preventing external disturbances and filtering noises.

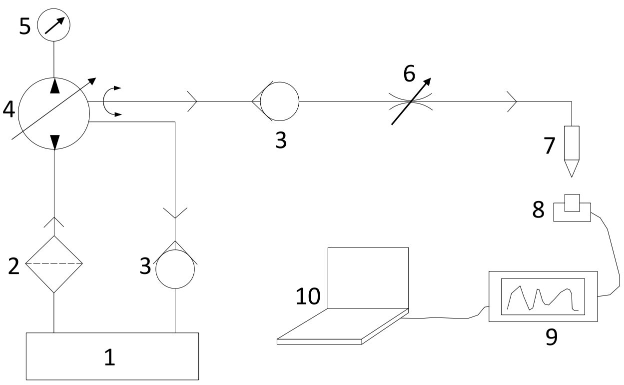
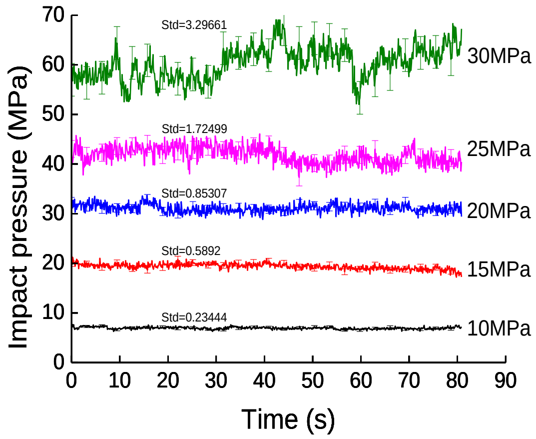



*Figure 2: Experimental system*

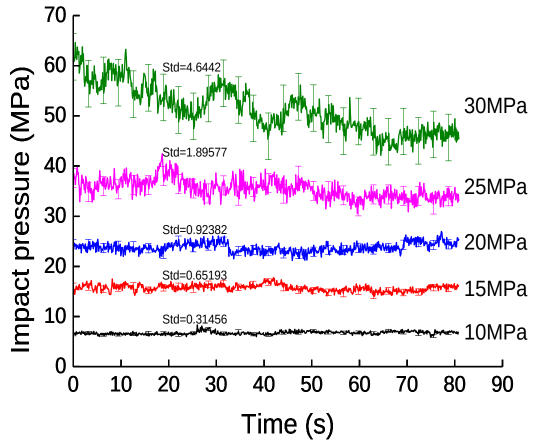
Note: 1-water tank; 2-filter; 3-check valve; 4-plunger pump; 5-pressure gauge; 6-throttle valve; 7-nozzle; 8-force transducer; 9-AMSY-6 host; 10-computer.
Five flow pressures (10, 15, 20, 25 and 30MPa) and three impact distances (20, 30 and 45mm) were selected to disclose the impact features of pulsed water jet. For comparison, continuous jet was also tested under the five flow pressures, but only at the impact distance of 45mm.

### 2.2 Results and Analyses

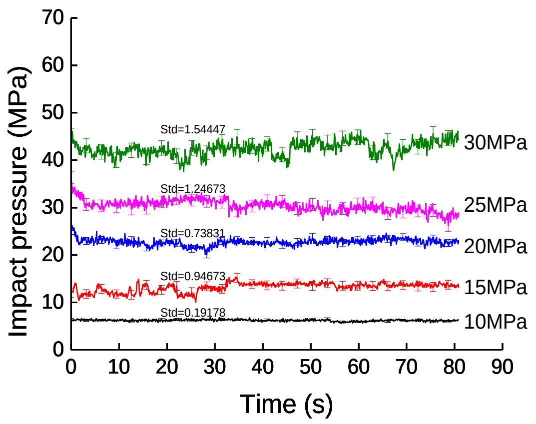
Figure 3 compares the impact force of pulsed jet and continuous jet at the impact distance of 20, 30 and 45mm. The following conclusions were drawn through the comparison:
(1) At a given impact distance, the impact pressure increased substantially with the increase of flow pressure. As shown in Figure 3(a), the impact pressure grew from less than 10MPa to over 60MPa as the flow pressure rose from 10MPa to 30MPa.
(2) With the increase in flow pressure, the pulsation became more and more dramatic. In Figure 3, the fluctuating amplitude (Std) widens rapidly from 10MPa to 30MPa.
(3) From Figures 3(c) and 3(d), it can be seen that the self-excited oscillation nozzle caused more fluctuations in the impact force.
(4) As the Helmholtz cavity produced feedback waves, the pulsed water jet had a stronger impact pressure than the continuous one. Besides, the impact pressure was way higher than the flow pressure at 20, 25 and 30MPa.



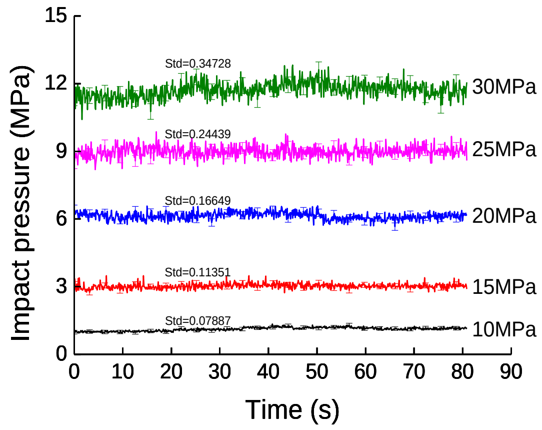

(a) 20mm, pulsed




(b) 30mm, pulsed




(c) 45mm, pulsed




(d) 45mm, continuous

*Figure 3: Comparison of the impact pressures of pulsed and continuous water jets*

## 3. Cutting application in chemical environments

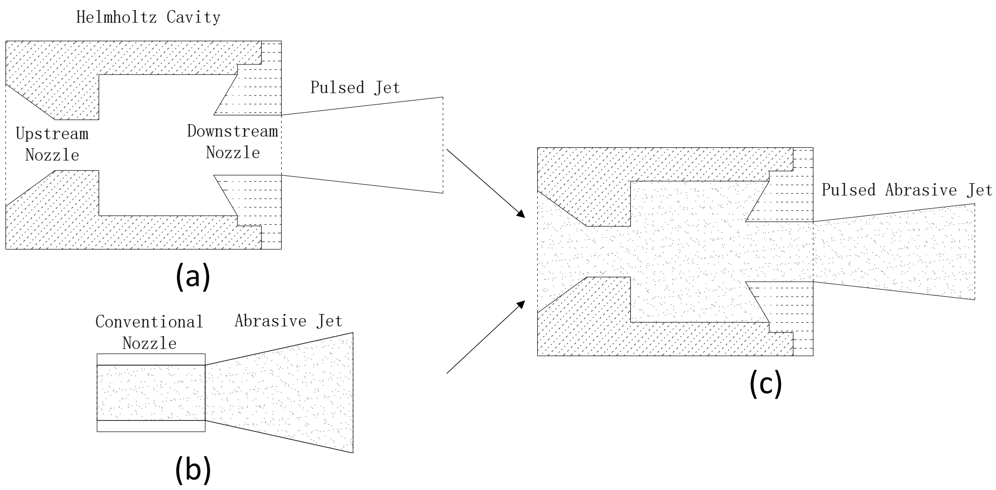



*Figure 4: Pulsed water jet with abrasives*

In chemical environments, it is often improper to utilize conventional cutting tools, such as hydraulic chain saw and gas cutting machine. Due to the presence of inflammables and explosives, any electricity leak or spark from the cutting tools will bring about serious consequences. To guarantee the cutting safety and effectiveness in chemical environments, it is necessary to discuss the applicability of the pulsed water jet to cutting.

Despite the high impact force, the pulsed water jet must be further enhanced to cut open metals. For this purpose, some abrasives were added into the jet (Figure 4). These additives achieve metal cutting mainly through abrasive formation, brittle cracking and plastic deformation (Orbanic, 2008; Hew, 2009; Pei, 2009; Li, 2016). Thanks to the excellent pressure-boost ability of pulsed jet, the abrasives can obtain a very high kinetic energy. Obviously, the pulsed jet acts as an accelerator and the abrasives execute the cutting mission (Hamatani, 1990; Kahlman, 1993; Momber, 1996).

**3.1 Equipment**

To meet the pressure demand for cutting, a pressure boost device was introduced to elevate the water source pressure. The whole cutting system was portable and mechanical-driven (Figure 5). The most important devices include a pressure-boost pump, an abrasive tank and a self-excited oscillation nozzle. During the cutting process, the water source drove the pressure-boost pump with low-pressure water flow; then, the pump sped up the velocity of water flow coming from another water source; next, the high-pressure water flow passed through the abrasive tank and got mixed with abrasives; finally, the pressurized abrasive water flow reached the self-excited oscillation nozzle, producing the pulsed abrasive water jet.

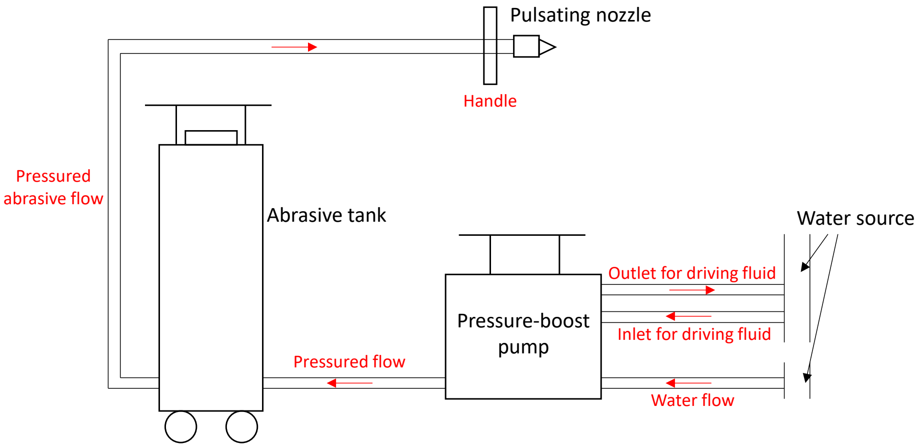



*Figure 5: Portable cutting system*

(1) Pressure boost pump

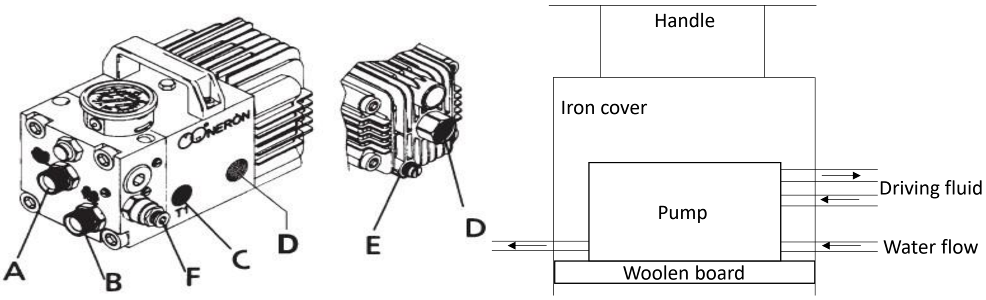
As mentioned above, the pressure boost pump was installed to elevate the relatively low flow pressure from the water source. Considering the target environment, the pressure boost pump was mechanically driven rather than electricity driven. The weight was substantially lightened and the scope of use was widened, as there is no need to consider anti-explosion enclosure and electricity demand.

Figure 6(a) shows the mechanical structure of the pressure boost pump. The pump was only 8kg in net weight and was driven by both water and emulsion. The maximum output pressure (40MPa) and flow rate (12L/min) were enough to produce a pulsed abrasive water jet. An iron cover was added to maintain the integrity of the pump, and a woollen board was introduced to suppress the noise. Thus, the final weight was less than 15kg. The appendices are shown in Figure 6(b).

(2) Abrasive tank

The abrasive tank is responsible for blending abrasives with water evenly. The impact force of the jet will be limited without sufficient blending. The volume of the tank was designed as 8L, so that the tank could be easily movable. The length and diameter of inner cavity were set to 500mm and 140mm, respectively. Considering the pressure and rust-proof requirements, the tank was made of martensitic stainless steel and able to withstand 40MPa of flow pressure.

As shown in Figure 7, the tank is comprised of three parts. In the upper part are an end cap and an inlet for abrasives. On the end cap, there is an atmospheric exhaust valve to release the air at the initial stage. The middle part is the blending cavity, where the high-pressure flow is mixed evenly with abrasives. In the lower part are the inlet and outlet passages. The inlet passage was designed particularly to blend the inlet flow with abrasives.




(a) (b)

*Figure 6: Pressure boost pump*

Note: A-low pressure water inlet; B-high pressure water outlet; C-driving flow inlet; D-driving flow outlet; E-safety valve; F-pressure limiting valve.

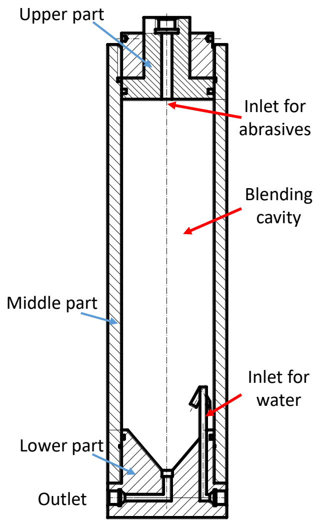



*Figure 7: Abrasive tank*

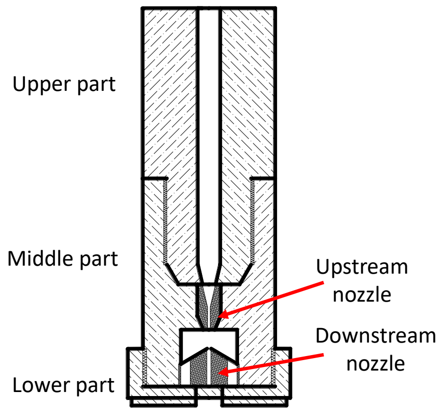



*Figure 8: Self-excited oscillation nozzle*

(3) Self-excited oscillation nozzle

Since the upstream and downstream nozzles need periodic replacement, the structure was assembled by three parts (Figure 8). The upstream/downstream nozzle is exposed as long as the upper or lower part is removed through a thread structure. In order to withstand high pressure, double-deck seal rings were adopted to prevent water leakage under 80MPa. For rust protection, the entire structure was made of stainless steel. The nozzles, as the most abraded parts, were made of hard alloy.

### 3.2 Verification

The author carried out a cutting experiment on two 150mm*80mm*30mm 45# steel blocks to verify the effect of the pulsed abrasive cutting system. The blocks were screwed onto the bench during the cutting. The nozzle was able to move along the axis. The target distance was set to 5mm and the flow pressure to 25MPa. The selected abrasives were 80-mesh garnets with a concentration of 6.3%.

According to the cutting results in Figure 9(a), it is obvious that the steel blocks were totally cut off by our system. The upper 10mm was cut open in 2min, the middle 10mm in 3.5min and the bottom 10mm in 10min. There was no spark throughout the cutting process. Hence, the pulsed abrasive jet system is effective, secure and worthy of promotion.

(a) steel block (b) fixed block (c) cutting result

*Figure 9: Cutting experiment of pulsed abrasive jet*

## 4. Conclusions

This paper applies the self-excited oscillation pulsed (SEOP) water jet to metal cutting in chemical environments. Firstly, the impact force of the water jet was compared with that of continuous jet under different flow pressures and at different target distances. The comparison shows that the impact force of pulsed water jet was much greater than that of the continuous jet. Secondly, some abrasives were introduced to the pulsed water jet to enhance its cutting ability, and a portable cutting system was assembled and examined in details. It was proved that the portable cutting system was convenient and effective for chemical environments.

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