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348
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Experimental research on performance parameters of a self-excited pulsed jet device

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Abstract

The self-excited pulsed jet is characteristically efficient and inexpensive. To develop an optimal pulsed jet, the structural and operating parameters affecting its peak hitting power were studied. The optimal range of cavity length and diameter, the areal ratio of the bottom and top nozzles, the bottom nozzle length, and the target distance and working pressure were all determined.

Key words: operating parameters, pulsed jet, self-excited, structural parameters

INTRODUCTION

The self-excited pulsed jet, developed on the basis of the theories of fluid mechanics, fluid elasticity, fluid resonance, underwater acoustics, etc., is efficient. The fluids passing through it form a self-excited oscillation within the structure, with no external exciting source, so that the continuous jet becomes pulsed. The instantaneous energy of a pulsed jet is several times higher than that of an otherwise similar continuous jet (Jiang & Liao 1998).

The self-excited pulsed jet has the advantages of a simple structure, easy processing, good sealing properties, high reliability, and low cost, etc. It is small and no additional driving mechanism is needed (Tang & Liao 1989), so, it has been widely used and developed.

The device's performance parameters have been studied using measurement techniques usually applied to flows inside fluid equipment (Yang *et al.* 2006). The optimal structural and operating parameters are discussed in this paper, which can be used as a reference for pulsed jet selection and design.

TEST APPARATUS AND METHODS

Test apparatus

The self-excited pulsed jet test apparatus is illustrated in Figure 1. During the test, pressurized water was supplied by a multistage, centrifugal pump (1), and the flow rate measured with an electromagnetic flowmeter (2). A gate valve (3) controls water pressure in line with the experimental design requirements. Water at the design working pressure forms a pulsed jet in the device (5), then sprays directly onto the target plate (6) equipped with a pressure transducer. Pressure signals are

Water Practice & Technology Vol 11 No 2
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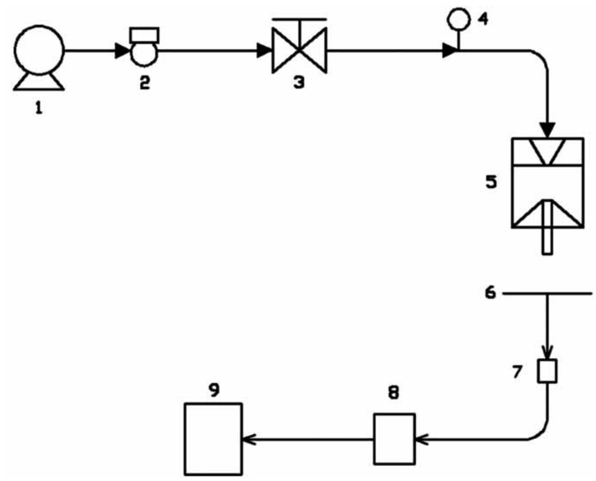

Figure 1 | Self-excited pulsed jet test setup. 1- Multistage centrifugal pump, 2- electromagnetic flowmeter, 3- gate valve, 4- pressure gage, 5- self-excited pulsed jet device, 6- target plate, 7- pressure transducer, 8- data acquisition system, and 9- computer.

passed to the data acquisition system (8) by a transducer (7), and stored and analyzed in a computer (9). The test system's structure is shown in Figure 2.

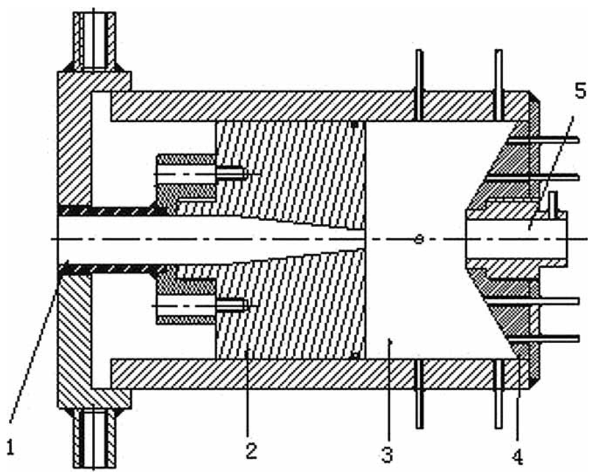

Figure 2 | Structure of a self-excited pulsed jet device. 1- Water inlet, 2- top nozzle, 3- self-excited oscillation cavity, 4- diffuser section, and 5- bottom nozzle.

Test method

The tests dealt with the structural and operating parameters of the self-excited pulsed jet influencing its hitting power. The structural parameters include, in particular: the diameter of the top nozzle, d_1, (8, 10, 12 mm), the diameter of bottom nozzle, d_2, (16, 17, 18, 20, 22, 24 mm), the length of the self-excited oscillation cavity, L_c, (30, 45, 55, 60, 75, 90 mm), the diameter of the cavity, D_c, (85, 95, 105, 120, 125 mm), and the length of the bottom nozzle, l_2, (40, 55, 80, 100 mm). The operating parameters include: the working pressure, P_1, (0.8, 1.0, 1.2, 1.4, 1.6, 1.8, and 2.0 MPa), and the target distance, L_f, (50, 150, 200, 300, 400, and 500 mm). The maximum and minimum fluid velocities, respectively, were 62.6 m/s and 39.6 m/s, and the maximum and minimum flow rates 43.4 m^3/h and 1.72 m^3/h.

Many proportioning tests of performance parameters were carried out under differing conditions, and the peak hitting power curves were obtained in relation to different parameter dimensions.

Water Practice & Technology Vol 11 No 2
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ANALYSIS OF EXPERIMENT RESULTS

Length of self-excited oscillation cavity (L_c)

The length of the oscillation cavity is the main structural parameter influencing pulse frequency. The peak hitting power corresponding to different cavity lengths was also studied. Test conditions were: $d_1 = 10$ mm, $d_2 = 14$, 16, 18, 20 mm, $D_c = 125$ mm, $L_f = 200$ mm, $L_c = 45$, 55, 60, 75, 90 mm. The peak hitting power curves are shown in Figure 3 and it is clear that the optimal pulsed jet has a cavity length of 45 mm.

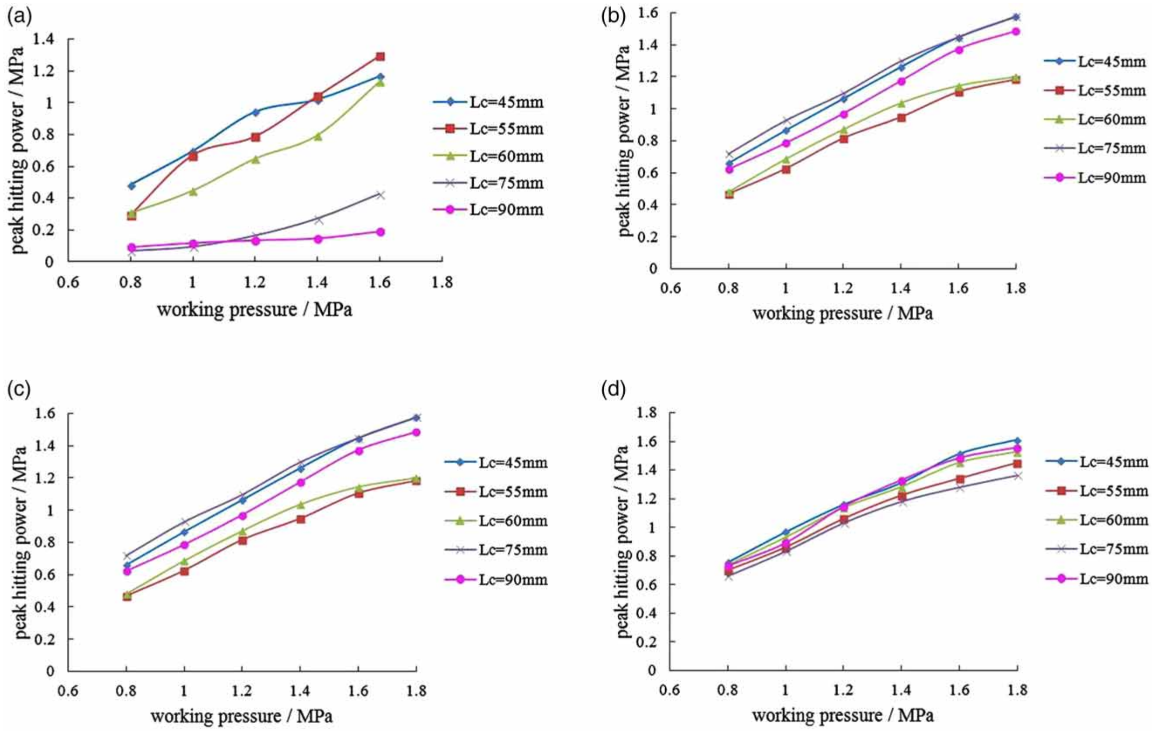

Figure 3 | Peak hitting power corresponding to different cavity lengths, d_2: (a) 14 mm, (b) 16 mm, (c) 18 mm, and (d) 20 mm.

Oscillation cavity diameter (D_c)

The oscillation cavity of the pulsed jet is main area where vorticity is transmitted. The diameter of the cavity influences the disturbance amplitude of vorticity directly. It also influences pulse frequency. The peak hitting power corresponding to different cavity diameters was therefore tested as well. Test conditions were: $d_1 = 10$ mm, $d_2 = 14$ mm, $L_c = 45$, 60, 75, 90 mm, $L_f = 200$ mm, and $D_c = 85$, 105, 120, 125 mm. Figure 4 shows the hitting power curves under different working conditions and it can be seen that the optimal cavity diameter is 120 mm, under the specific conditions tested.

Areal ratio of bottom and top nozzles ($m = d_2^2/d_1^2$)

The size of the top nozzle determines the jet's radius and flow, while the bottom nozzle's size affects its efficiency. The bottom/top nozzle areal ratio (m) is, thus, a major factor influencing pulsed jet formation, so the peak hitting power corresponding to different areal ratios was also

Water Practice & Technology Vol 11 No 2
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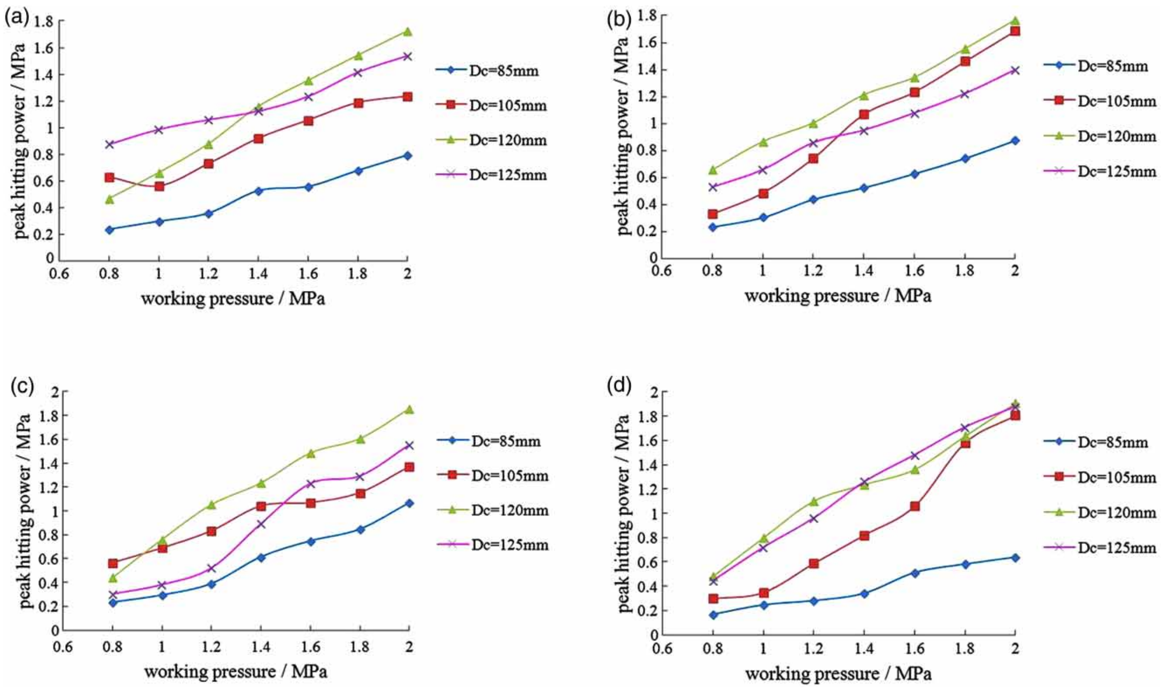

Figure 4 | Peak hitting power corresponding to different cavity diameters, L_c: (a) 45 mm, (b) 60 mm, (c) 75 mm, and (d) 90 mm.

studied. Test conditions were: $d_1 = 10$ mm, $D_c = 125$ mm, $L_f = 200$ mm, $L_c = 45$, 60, 75, 90 mm. The results – Figure 5 – show that when the areal ratio is between 3.24 and 4.84, the pulsed jet's hitting power is at its best, under the conditions tested.

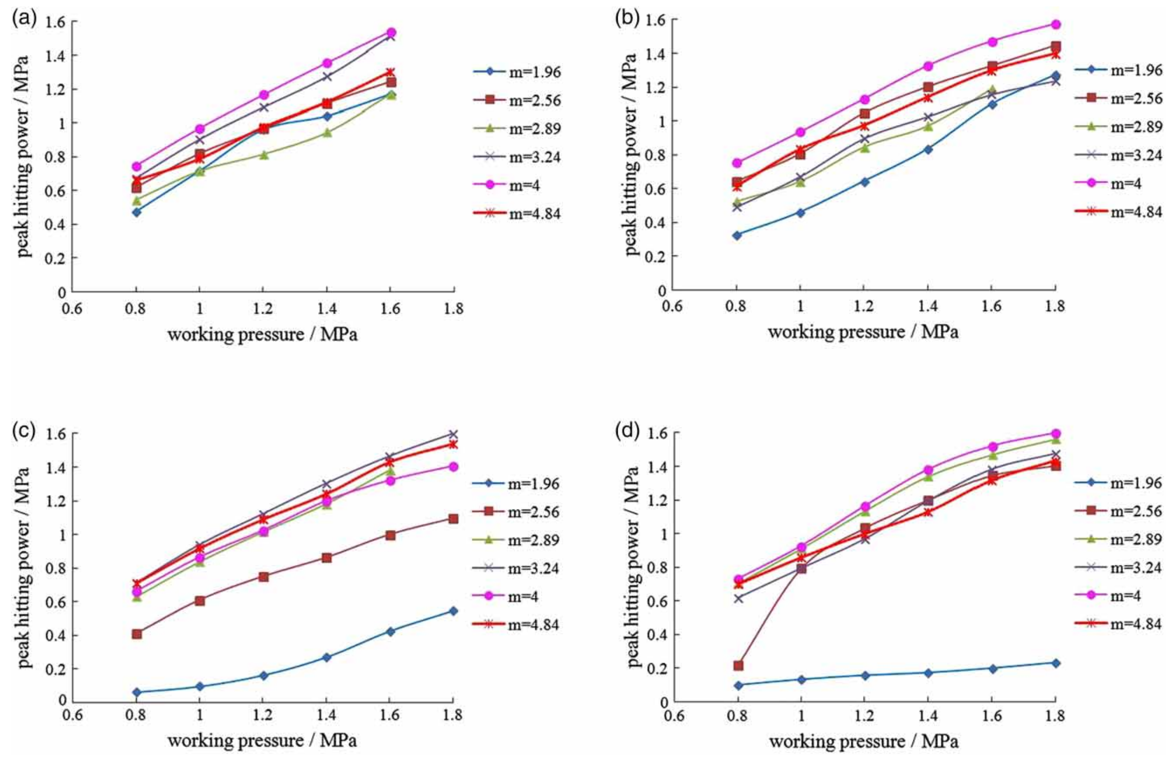

Figure 5 | Peak hitting power corresponding to different bottom/top nozzle areal ratios, with different oscillation cavity lengths, L_c: (a) 45 mm, (b) 60 mm, (c) 75 mm, and (d) 90 mm.

Water Practice & Technology Vol 11 No 2
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Bottom nozzle length (l_2)

The pulsed jet develops fully at the bottom nozzle, so the latter's length should be suitable for forming the optimal pulse. The conditions for testing the influence of the nozzle's length were: $d_1 = 8$ mm, $d_2 = 14$ mm, $D_c = 85$ mm, $L_c = 60$ mm, $L_f = 50$ mm. The peak hitting power corresponding to different lengths is shown in Figure 6, and the variation in the hitting power signal with time in Figure 7. It is clear that the jet's peak hitting power is almost the same regardless of bottom nozzle length. When l_2 is 55 mm, however, there is a clear pulse phenomenon and transient pressure mutation, showing that the bottom nozzle's length has an important influence on pulsed jet formation. These results indicate that the pulsed jet is optimal when bottom nozzle length is 55 mm, under the conditions tested.

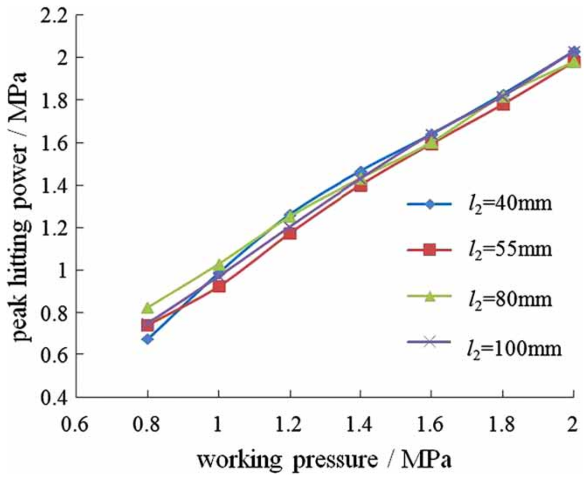

Figure 6 | Pulsed jet peak hitting power corresponding to different bottom nozzle lengths.

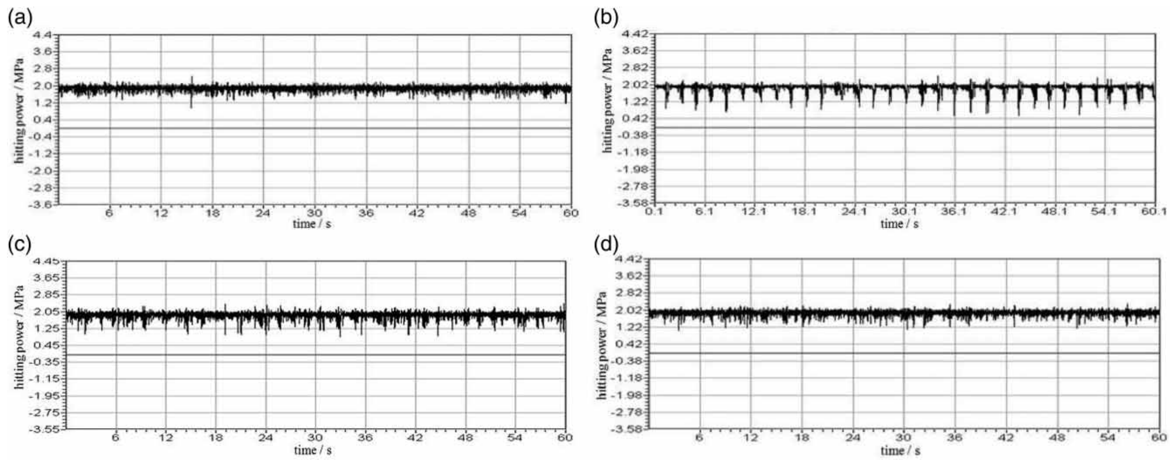

Figure 7 | Hitting power signal corresponding to different bottom nozzle lengths, l_2: (a) 40 mm, (b) 55 mm, (c) 80 mm, and (d) 100 mm.

Target distance (L_f)

The target distance affects both the hitting power and area of the jet, and thus the jet's action on the target. Because of this, it influences its erosive power. The impact of target distance on effective hitting power was tested using: $d_1 = 8$ mm, $d_2 = 16$ mm, $D_c = 85$ mm, $L_c = 90$ mm, $P_1 = 0.8$, 1.0, 1.2, 1.4, 1.6, 1.8, and 2.0 MPa. As can be seen in Figure 8, the optimal target distance of the pulsed jet, under the conditions tested, is between 150 and 200 mm.

Water Practice & Technology Vol 11 No 2
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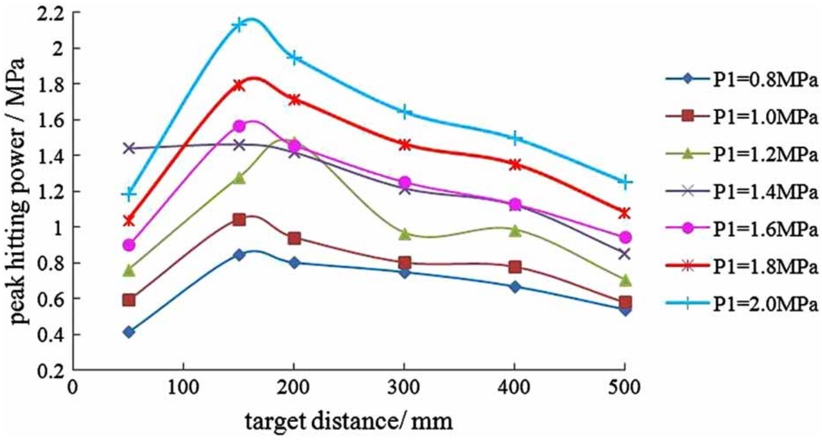

Figure 8 | Peak hitting power corresponding to different target distances.

There is no clear reason why the curves relating to operating pressures of 1.2 and 1.4 MPa do not fit the general pattern fully, especially at and around what seems to be the optimum target distance. In principle, jets at these pressures should operate in the same way as those pressures both above and below this range. Further work is in hand to try to understand what happens/happened.

Working pressure (P_1)

Working pressure is a major operating parameter for the pulsed jet and affects its hitting power directly. The relationship between working pressure and hitting power was studied under the following conditions: $d_1 = 10$ mm, $d_2 = 18$ mm, $D_c = 125$ mm, $L_c = 90$ mm, $L_f = 200$ mm, and, $P_1 = 0.8$, 1.0, 1.2, 1.4, 1.6, 1.8, and 2.0 MPa. Figure 9 shows the peak hitting power curves for pulsed and continuous jets. It can be seen that a pulsed jet has about 30% greater hitting power than a continuous jet under the same working conditions, and that greater working pressure yields greater hitting power. Self-excited jet pulses can occur at working pressures between 0.8 and 1.8 MPa.

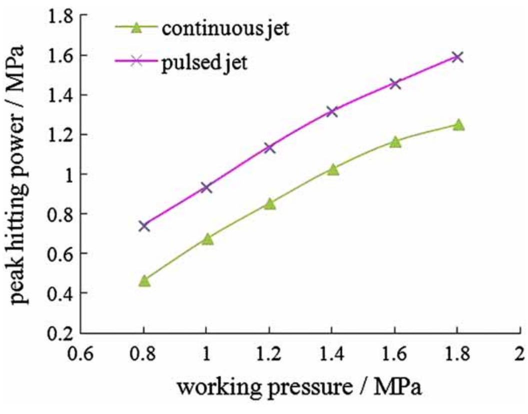

Figure 9 | Peak hitting power curves for pulsed and continuous jets.

CONCLUSIONS

The performance parameters of the self-excited pulsed jet were studied. The results show that an optimal pulsed jet has: cavity length 55 mm, cavity diameter 120 mm, bottom/top nozzle areal ratio between 3.24 and 4.84, and bottom nozzle length 55 mm, when it is operated at a working pressure

Water Practice & Technology Vol 11 No 2
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between 0.8 and 1.8 MPa, and the target distance is between 150 and 200 mm. Now, further work is being studied as to whether the conclusions are suitable for all types of pulsed jets.

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