Design and Manufacturing of a Water Jet Cutter

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ARTICLE INFO

ABSTRACT

In a phase when “better, faster, cheaper” are words to live by in the manufacturing world, this paper aims in modelling and manufacturing of water jet cutter machine. The experimental apparatus consists of nozzle, piston pump and single-phase 2hp motor. It is used for the cutting of soft materials like wood, rubber and thermopore at a pressure of 60 bars. This pure water jet cutting machine based on the principle of increasing the pressure and discharge the water through the orifice. An experimental study was also conducted on the design of orifice and find the effect on cutting velocity by changing the diameter of orifice. The diameter varies from 1mm to 3mm. During modelling the factors that appears to be influential are pump pressure, water jet velocity, impact force and orifice diameter.

Keywords: Modelling, Impact force, water jet velocity

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1. Introduction

A water jet cutter is machine that uses a jet of water having high pressure and high velocity that cuts the metal or other different material. The process of water jet cutting is same as the process of water erosion in nature but the acceleration and concentration depend on the magnitude. [1] For the fabrication and manufacturing of the parts of the machinery and all other devices water jet cutter is used. It has a variety of applications. It is used in mining industry, aerospace industry for performing different operations like cutting, reaming, shaping and carving.[2] This method is used during the cutting of material when they are sensitive to high temperature. This method is preferred over other cutting methods because it can generate less heat during the process of cutting of any material. [3] Water jet has to fulfil three functions in case of cutting, cooling, removal of cutting debris and cutting. In automotive industry, it is used for the cutting of carpets and also used in the cutting of Paper in paper industry but nowadays they are limited to the cutting of soft and non-metallic materials. The most common way for the cutting of material is the pure water jet cutting. Different kind of materials can be cut by using this technology.[4]
Pure Water Jet (PWJ) is a term utilized for explicitly recognize water stream without abrasive. As PWJ utilizes the emission of beam leaving the hole to cut legitimately, it is fundamentally utilized only for delicate material like food, garments, rubber, elastic, pieces of candy or slim delicate wood, yet isn't successful for cutting harder materials. [5] The hole measurements utilized in PWJ applications are little (somewhere in the range of 0.05 and 0.15 mm) so as to form an ultra-thin stream and concentrate all the vitality in the littlest conceivable region to improve cutting force. [6]

2. Methodology

Pure water jet cutting is used for the cutting pf soft materials like rubber, thermopore, wood etc. Water is pumped from the reservoir by high pressure pump and pressure of water is increased to required value. Then high-pressure water is moved toward accumulator which is a temporary storage of water. After that high pressure of water is passed through the nozzle and there is an increase in the kinetic energy and as a result of its high velocity is produced. When water hits the workpiece, stress is produces [7]

![Schematic diagram of water jet cutter](image)

The main components of water jet cutting machine are pump, motor, nozzle, reservoir and catcher.

3. Calculations and Results

The main content of calculations on which our project basically relies are given below:

- Pump and motor selection
- Jet velocity
- Nozzle inlet and outlet diameter
- Impact force

3.1 Pump and motor selection [8][9]

\[ P_w = \rho Q g H \] \hspace{1cm} \ldots (1)

Since \( H = \frac{\Delta P}{\rho g} \) \hspace{1cm} \ldots (2)
We know that required pressure to cut the particle/chip board is 2 MPa

So,

\[ H = \frac{2 \times 10^6}{1000 \times 9.81} \]

\[ = 203.87 \text{m} \]

We measure the flow rate required to produce the velocity which is enough to cut a material by the help of a beaker and stop i.e.

We knew the volume of the beaker (\( V \)) and time (\( t \)) to pour the known volume of the beaker. After calculating we got flow rate which is 30 lpm.

\[ Q = 30 \text{ lpm} \]

And

\[ \frac{30}{60 \times 1000} = 5 \times 10^{-7} \text{ m}^3 \text{s}^{-1} \]

By putting the values of \( \rho, Q, g \text{ and } H \text{ in equation} (1) \)

\[ P_w = 1000 \times 5 \times 10^{-4} \times 9.81 \times 203.87 \]

\[ P_w = 999.98 \approx 1000 \text{ W} \]

\[ = \frac{1000}{746} = 1.34 \approx 2 \text{ hp} \]

3.2 Jet velocity

The modelling of the water jet machining process depends upon some principles of fluid dynamics.[10]. One of the most important principle is Bernoulli’s principle which is as follow:

\[ P + \frac{\rho V^2}{2} + \rho gh = \text{constant} \]

where,
- \( p \) - water pressure,
- \( v \) - velocity of water,
- \( \rho \) - water density,
- \( g \) – gravitational acceleration
- \( h \) – height from the ground
\[ P + \frac{\rho V^2}{2} + \rho g h_1 = P + \frac{\rho V_j^2}{2} + \rho g h_2 \]

**Figure. 2.** Bernoulli’s theorem applied to water jet machining

\[ P - P_{at} = \frac{1}{2} \rho (V_j^2 - V^2) + \rho g (h_1 - h_2) \]

For \( P_{at} \ll P; V_j^2 \gg V^2; h_1 \approx h_2 \)

\[ P = \frac{1}{2} \rho V_j^2 \]

To simplify the expression, few assumptions are made. The assumptions are as follows:

The difference of height is neglected.[11][12].

Speed of the water at nozzle entrance is negligible as compared to the speed of the jet at the exit of the nozzle.

The atmospheric pressure is smaller than the water pressure at the entrance to the nozzle.

\[ V_w = \sqrt{\frac{2P}{\rho W}} \]

\( P = 900 \text{ psi} = 6 \text{ MPa} \)

\( \rho = 10000 \text{ kg/m}^3 \)

By putting it in the above equation

\[ V_w = \sqrt{\frac{2 \times 6 \times 10^6}{1000}} \]

\[ = 109.54 \text{ m/s} \]

### 3.3 Nozzle inlet and outlet diameter

By using continuity equation [13]

\[ Q = A_1 v_1 = A_2 v_2 \]

Also,

\[ Q = A_0 v_j \]

\( A_0 = \) orifice area

\( V_j = \) jet velocity

We know that
Q = 30 LPM or $5 \times 10^{-4} \text{m}^3/\text{s}$

And

$v_j = 109.54 \text{ m/s}$

By putting value of $Q$ and $v_j$ in continuity equation

$5 \times 10^{-4} = A_0 \times 109.54$

$A_0 = \frac{5 \times 10^{-4}}{109.54}$

$\pi d_0^2 \frac{2}{4} = 4.56 \times 10^{-6}$

$d_0^2 = 4.56 \times 10^{-6} \times \frac{4}{\pi}$

$d_0^2 = 5.81 \times 10^{-6}$

$d_0^2 = 2.41 \times 10^{-3}$

$d_0 = 2.41 \text{ mm}$

After doing the number of experiments with the nozzle of diameter 2.4mm but this was not enough to produce the velocity which will cut the desire material so in order to overcome this problem we reduce the diameter of nozzle to increase in velocity decrease flow rate in constant.

$Q = Av$

As in the above equation in order to increase velocity we have to reduce area which means the diameter of nozzle [14]

$Q = \downarrow A \uparrow v$

So, we tried difference number of experiment and cutting of soft material tart from diameter of 1mm. So, we set the diameter to 1mm also it was feasible for us to make the nozzle of the 1mm per market survey.

So,

Now,

$d = 1\text{mm}$

$A = \frac{\pi d^2}{4} = \frac{\pi (1 \times 10^{-3})^2}{4}$

$A = 7.85 \times 10^{-7} \text{ m}$
So, to find the jet velocity again with new area of nozzle

\[ Q = A_0 v_j \]

\[ 5 \times 10^{-4} = 7.85 \times 10^{-4} \times V_j \]

\[ V_j = \frac{5 \times 10^{-4}}{7.85 \times 10^{-7}} \]

\[ = 636.94 \text{ m/s} \]

So, the velocity of jet is in between 109.5 to 636.94 m/s

Inlet diameter of nozzle is 3mm.

3.4 Impact force

In order to find out the impact force exerted by the waterjet on surface of material we use the fundamental law of conservation of mountain. [15]

\[ \dot{m} v_1 = \dot{m} v_2 \]

\[ F = \dot{m} v_2 - \dot{m} v_1 \]

\[ \dot{m} (v_2 - v_1) \]

After hitting the material of velocity of jet become zero

\[ v_2 = 0 \]

\[ F = -\dot{m} v_1 \text{ (-ve sign shows the direction)} \]

\[ = \rho \dot{v} v_1 \]

\[ (\dot{v} = A \nu) \]

\[ \rho A \nu \cdot v_1 (v=v_1) \]

\[ F = \rho A \nu^2 \]

We know the velocity of jet area of orifice and density of water so by putting formulae

\[ F = 1000 \times \frac{\pi (1 \times 10^{-3})^2}{4} \times (636.94)^2 \]

\[ F = 318.63 \text{N} \]
3.5 Project specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure</td>
<td>60bars/870psi</td>
</tr>
<tr>
<td>Motor</td>
<td>2 hp single phase</td>
</tr>
<tr>
<td>Pump flow rate</td>
<td>41 LPM</td>
</tr>
<tr>
<td>Nozzle inlet diameter</td>
<td>3mm</td>
</tr>
<tr>
<td>Nozzle outlet diameter</td>
<td>1mm</td>
</tr>
<tr>
<td>Pipe diameter</td>
<td>27mm</td>
</tr>
<tr>
<td>Nozzle material</td>
<td>nickel</td>
</tr>
<tr>
<td>Pipe material</td>
<td>steel</td>
</tr>
</tbody>
</table>

3.6 Final results

Cutting of following material would be done as per specifications:

<table>
<thead>
<tr>
<th>MATERIALS</th>
<th>THICKNESS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chip board</td>
<td>1mm-5mm</td>
</tr>
<tr>
<td>Rubber</td>
<td>1mm-5mm</td>
</tr>
<tr>
<td>Thermopore sheet</td>
<td>5mm-100mm</td>
</tr>
<tr>
<td>Corrugated fiber board</td>
<td>1mm-8mm</td>
</tr>
</tbody>
</table>

3.7 Cad model

Solidworks is used for the complete cad modelling of the project.

Figure 3. Cad Model
Cutting specimens

Figure 4. Cutting of particle board/chip board

Figure 5. Cutting of corrugated fibre board

Figure 6. Cutting of rubber

Figure 7. Cutting of thermopore sheet

The impact force of water jet is applied on a area of 1mm² of the different materials. So the cutting is performed on a unit area of the materials.

Figure 8. Overall Project Narration
4. Conclusion

In this project complete model of pure water jet cutter is fabricated in the workshop with required raw materials and different components. This low-pressure water jet cutter operates on 60 bars pressure and used for the cutting of soft materials like wood, rubber, thermopore etc. with higher accuracy. Before that by using computer aided design tools a detailed design of functional sub systems was made. For this purpose, solid work is used which is very good in design and analysis.

The components that were designed include base table, nozzle, nozzle holder and total piping system. By using the available materials like steel, iron nickel and pipes final components were fabricated in the workshop. In industries water jet cutter of high pressure are used but a successful experiment is done on low pressure water jet cutter and cut different soft materials at low pressure. Experiment were conducted on the orifice design and find the effect on cutting velocity. Velocity increases as the diameter decreases and cutting efficiency increases.

Future prospect

In future, the machine is automated using micro controller driver stepper motor combination. This is used to automate the nozzle which can move in x and y direction and also for the table movement. As a result, this can increase the safety factor.

Acknowledgement

This research was funded by HITEC University Taxila Cantt, Punjab, Pakistan

References


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