# TAGUCHI APPROACH TO DETERMINE THE INFLUENCE OF THE PROCESS PARAMETERS IN CLEANING WATER JETS

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**ABSTRACT**:. In the late 1950s, when reliable high pressure pumps were built, the usage of water jets spread widely in the field of pipes and sewerage cleaning. In our particular case, water jets between 100 and 200 bars pressure are being used. Operational behaviour of these systems is dependent on the process parameters, which can vary, causing variations of the impact force. To determine the influence of process parameters on impact forces from the sewerage system cleaning head, Taguchi method was used. In order to measure the impact forces between the water jet and a flat and rigid surface, we designed and built a stand for generating pressure water jets, as well as a device to measure the impact forces.
**KEY WORDS**: Taguchi method, water jet, impact force, process parameters.

## 1 INTRODUCTION

Phenomena that occur in the cleaning water jets are complex. (Adler, 1979) describes mechanisms occurring at the impact of a jet with a surface. (Leach & all, 1966), (Leu & all, 1998) and (Guha & all, 2011) analysed pressure distribution along centerline of the water jet. A number of papers have studied the influence of nozzle geometry on water jet (Annoni & all, 2008), (Ghassemieh & all, 2006), (Liu & all, 2010).

The aim of this paper is to determine the influence of process parameters on impact forces from the sewerage system cleaning head. In order to measure the impact forces between the water jet and a flat and rigid surface, we designed and built a stand for generating pressure water jets, as well as a device to measure the impact forces. In the measurements, water jets between 100 and 200 bars pressure have been used. The values of these pressures correspond to low pressure water jets (Momber, 2003).

To carry out an experimental research, is recommended to follow a series of steps (Montgomery, 2013):

- recognition of and statement of the problem;
- selection of the response variable;
- choice of factors (process parameters), levels, and ranges;
- choice of experimental design;
- performing the experiment;
- statistical analysis of the data;
- conclusions and recommendations.

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## 2 APPARATUS USED AND METHODOLOGY OF THE MEASUREMENTS

In order to measure the impact forces between the water jet and a flat and rigid surface, we designed and built a stand for generating pressure water jets, as well as a device to measure the impact forces (Medan, 2012).

### 2.1 The stand to generate pressure water jet

Schematic diagram of the stand to generate pressure jet is shown in figure 1.

Component parts of stand: 1) electric motor, 2) flexible coupling, 3) high pressure pump, 4) pressure regulator, 5) pressure gauge, 6) nozzle, 7) tap water, 8) water tank, 9) chassis.

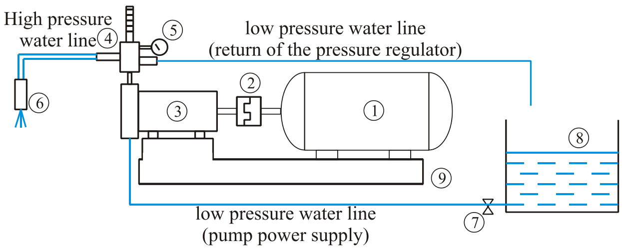


**Figure 1. Schematic diagram of the stand to generate pressure jet**

Water coming out of the high pressure pump (3) goes into the pressure regulator (4). Through it adjusts the pressure and flow of water in the path of the high pressure water. This pressure corresponds to the one at the outlet of nozzle.

### 2.2 The device to measure the impact forces

In figure 2 is represented the principle diagram of the device for the measurement of the impact force of the water jet and a flat and rigid surface.

Main component parts of the device are: 1) high-pressure water hose, 2) support nozzle, 3) nozzle block, 4) nozzle, 5) water jet, 6) flat and rigid target plate, 7) collection path water, 8) scaled container for measurement of the flow of water jet, 9) piezoelectric sensor mounting, 10) piezoelectric sensor, 11) data acquisition Personal Daq/3000, 12) computer for the processing of data; 13) support plate, 14) acrylic tube, 15) rods for adjusting distance x.

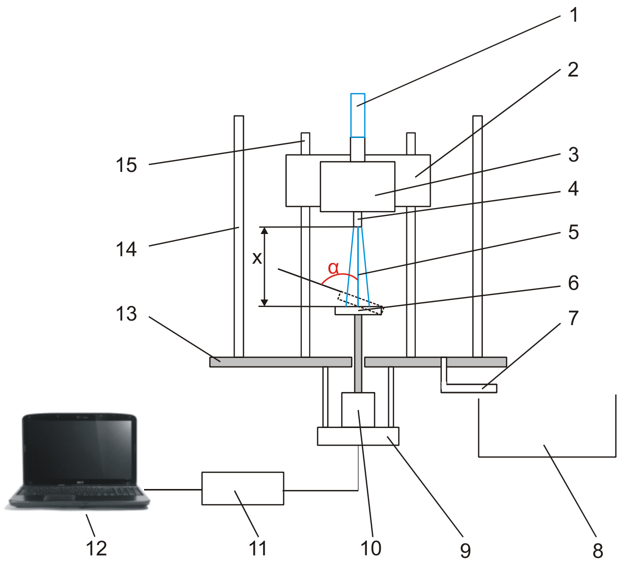


**Figure 2. Diagram of the device for the measurement of the impact force of the water jet**

From high pressure water hose (1) come water at a certain pressure p desired. At the outlet of nozzle is generated a water jet (5) that striking target plate (6), who it located at a certain distance x in front of the nozzle. The jet (5) generates a impact force at a time when he meets target plate (6). This force produces axial movement of target plate. This movement is converted into an electric signal by the piezoelectric sensor (10). Electrical signal is collected by data acquisition Personal Daq/3000 (11), which forward data to a computer (12) using DaqView soft processes data actually obtained.

# 3 TAGUCHI METHOD

## 3.1 Establishment of process parameters

The process parameters that influence the impact force are (Medan, 2012):

1) D – nozzle diameter, [mm];

2) p – water pressure, [bars];

3) x – distance between the nozzle and impact surface, [mm];

4) α - impact angle (angle formed by the jet and impact surface), [$^O$].

The value of diameter of nozzle are D=1mm, 1,5mm and 2mm. These are common values used in equipment to maintenance and cleaning of sewers.

The pressures used to perform the measurements have the values p=100 bars, 120bars, 140bars, 160bars, 180bars and 200bars. For the maintenance sewers, are used high pressure water pumps which generate a maximum pressure of 200 bars.

To perform the measurements distance x has been fixed at the values x=25 mm, 50 mm, 75 mm, 100 mm, 125 mm, 150 mm, 175 mm and 200 mm.

The impact angle α has values $60^O$, $75^O$ and $90^O$. For cleaning heads usual value of the angle of impact α is $75^O$. If impact angle α decrease below $60^O$ lead to a drop in of the impact forces.

## 3.2 Setting the levels for process parameters

For each of the 4 parameters set out above, two levels were selected a minimum and a maximum values. The values of these levels are even extreme values for each of the parameters.

Table 1 presents the parameters and levels chosen for this study.

**Table 1. Process parameters and level values**

| Abbre-viation | Para-meter number | Name | Value 1 minimum Notation 1 | Value 2 maximun Notation 2 |
|---|---|---|---|---|
| A | 1 | Nozzle diameter | 1 mm | 2 mm |
| B | 2 | Pressure | 100 bars | 200 bars |
| C | 3 | Distance x | 25 mm | 200 mm |
| D | 4 | Angle α | $60^O$ | $90^O$ |

## 3.3 Establishing the experimental plan using Taguchi method

Choosing an array of experiences is causing total degrees of freedom required.

Calculate the degrees of freedom to set parameters and degrees of freedom associated with the interactions between parameters.

The degrees of freedom associated factors are calculated with formula:

$$GL_f = N_f \cdot (N_n - 1) \tag{1}$$

where:

- $N_f$ represented the numbers of factors,
- $N_n$ represents the number of levels for each factor, in this case has the value 2.

By replacing the values in the equation (1) is obtained:

**Table 2. The measured force F according to the parameters set**

| No. of experiment | Parameters | | | | Impact force F [N] | | | |
|---|---|---|---|---|---|---|---|---|
| | Diameter D [mm] | Pressure P [bar] | Distance x [mm] | Angle α [°] | 1 | 2 | 3 | $F_{med}$ |
| 1 | 1 | 100 | 25 | 60 | 8.08 | 7.69 | 7.94 | 7.90 |
| 2 | 1 | 100 | 25 | 90 | 10.49 | 10.48 | 10.36 | 10.44 |
| 3 | 1 | 200 | 200 | 60 | 14.79 | 14.92 | 14.55 | 14.75 |
| 4 | 1 | 200 | 200 | 90 | 19.32 | 18.70 | 19.08 | 19.03 |
| 5 | 1 | 100 | 200 | 60 | 6.39 | 6.15 | 6.40 | 6.31 |
| 6 | 1 | 100 | 200 | 90 | 7.84 | 7.83 | 8.03 | 7.90 |
| 7 | 1 | 200 | 25 | 60 | 17.12 | 16.98 | 16.69 | 16.93 |
| 8 | 1 | 200 | 25 | 90 | 21.67 | 21.72 | 21.83 | 21.74 |
| 9 | 2 | 100 | 200 | 60 | 29.06 | 29.94 | 29.46 | 86.07 |
| 10 | 2 | 100 | 200 | 90 | 36.97 | 36.71 | 36.21 | 30.95 |
| 11 | 2 | 200 | 25 | 60 | 65.37 | 65.10 | 64.80 | 65.09 |
| 12 | 2 | 200 | 25 | 90 | 86.00 | 85.98 | 86.24 | 86.07 |
| 13 | 2 | 100 | 25 | 60 | 30.82 | 31.31 | 30.72 | 30.95 |
| 14 | 2 | 100 | 25 | 90 | 40.44 | 40.30 | 40.18 | 40.30 |
| 15 | 2 | 200 | 200 | 60 | 59.95 | 59.47 | 60.14 | 59.85 |
| 16 | 2 | 200 | 200 | 90 | 76.32 | 76.30 | 76.35 | 76.32 |

$$GL_f = 4 \cdot (2-1) = 4 \quad (2)$$

The degrees of freedom associated interactions are calculated with formula:

$$GL_i = N_i \cdot (N_n - 1) \quad (3)$$

where:

$N_i$ represented numbers of interactions.

Is obtained:

$$GL_i = 6 \cdot (2-1) = 6 \quad (4)$$

The total number of degrees of freedom calculated:

$$GL_t = GL_f + GL_i = 10 \quad (5)$$

$$\begin{pmatrix} 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 2 \\ 1 & 2 & 2 & 1 \\ 1 & 2 & 2 & 2 \\ 1 & 1 & 2 & 1 \\ 1 & 1 & 2 & 2 \\ 1 & 2 & 1 & 1 \\ 1 & 2 & 1 & 2 \\ 2 & 1 & 2 & 1 \\ 2 & 1 & 2 & 2 \\ 2 & 2 & 1 & 1 \\ 2 & 2 & 1 & 2 \\ 2 & 1 & 1 & 1 \\ 2 & 1 & 1 & 2 \\ 2 & 2 & 2 & 1 \\ 2 & 2 & 2 & 2 \end{pmatrix}$$

**Figure 3. Orthogonal array $L_{16}$ ($2^4$), according to Taguchi method**

Number of degrees of freedom of the matrix of experiences must be at least 10 (minimum 10 experiments).

According to Taguchi method nearest array of experiences that meet the condition is the matrix $L_{16}(2^4)$ (figure 3).

For each of the 16 experiments (determined according to the Taguchi experiments) three sets of measurements of the impact force were performed. For each experiment was determined the average force ($F_{med}$). The data are summarized in table 2

## 3.4 Calculation of parameters influence the impact force

The medium effect of the Y factor at level i is calculated with formula:

$$E_{Yi} = R - R_{med} \quad (6)$$

Where:

- R represents the average responses when the factor Y is at the level i;
- $R_{med}$ represents the overall average responses.

With formula (6) was calculated the average effects for the four parameters, for two levels, minimum and maximum. The calculated values are summarized in table 3.

Figure 4 shows the main effects plot for means of the parameters on the impact force.

**Table 3. Effects of parameter values on the impact force**

| $E_{A1}$ | $E_{A2}$ | $E_{B1}$ | $E_{B2}$ | $E_{C1}$ | $E_{C2}$ | $E_{D1}$ | $E_{D2}$ |
|---|---|---|---|---|---|---|---|
| 13.13 | 53.09 | 21.24 | 44.97 | 34.93 | 31.29 | 28.91 | 37.31 |

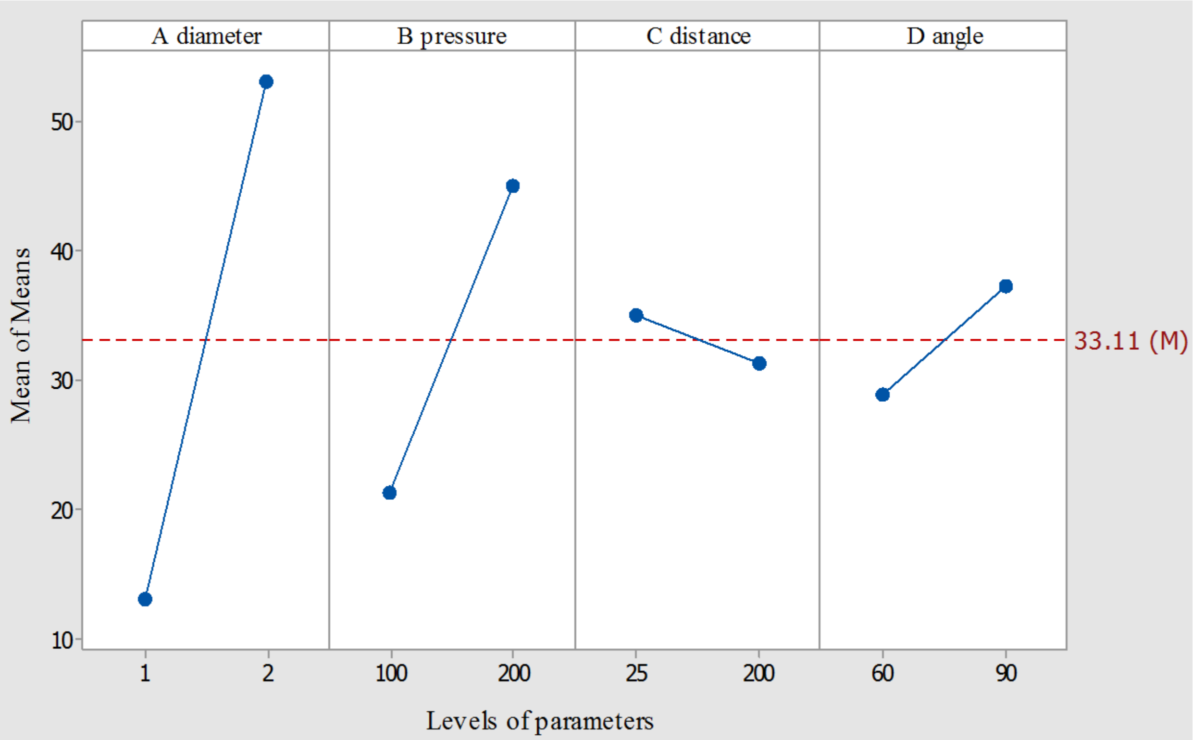


**Figure 4. Orthogonal array $L_{16}$ ($2^4$), according to Taguchi method**

## 3.5 Calculation of the interactions parameters

In Figure 5 is shown the graph corresponding interactions of the four parameters.

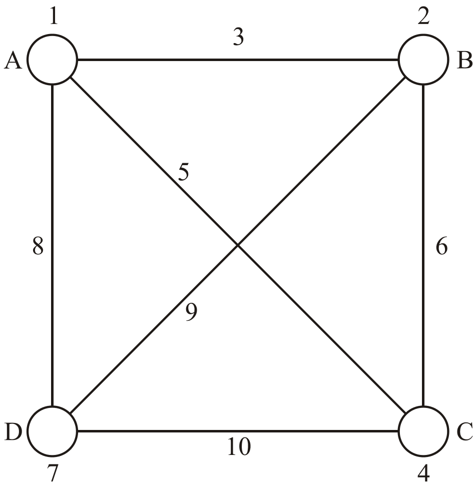


**Figure 5. Graph corresponding to plan of experiments $L_{16}$ ($2^4$)**

To observe the influence of interactions between the studied parameters on the impact force starts from a tabular layout of the mean parameters the two corresponding values, followed by a simple mathematical calculation.

The effect of the interaction between the two factors A and B are calculated according to the formula:

$$I_{YiZj} = RY_iZ_j \qquad (7)$$

where:

- $R_{YiZj}$ represents the average responses when the factor Y is at the level i and the factor Z is at the level j.

With formula (7) is calculated the effect of interactions for all four parameters for the two levels of minimum and maximum.

These values are used for plotting interactions between parameters to see the effect on the impact force (figure 6).

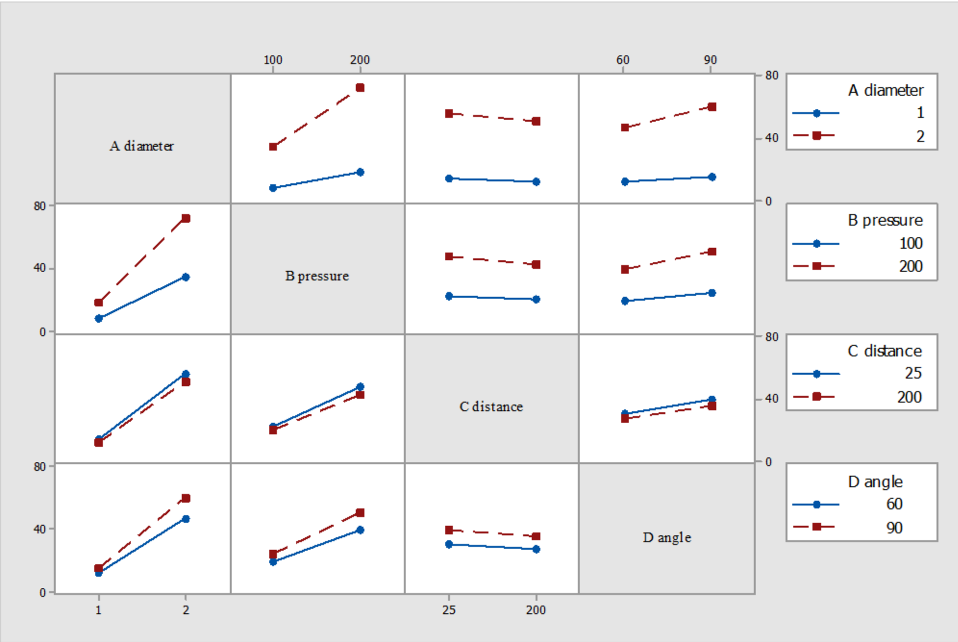


**Figure 6. Interaction plot for means**

## 3.6 Calculation of percentage of influence of parameters and their interactions on the impact force

Table 4 presents the formulas and values for determining the percentage of parameters and interactions influence the impact force.

**Table 4. The analysis of the influence and interactions**

| Factors | Deviation sum of square | Factor/Interaction | Calculated values [N] |
|---|---|---|---|
| Y | $SPA_Y = \frac{N}{n_Y}\sum_{i=1}^{i=n_Y} E_{Y_i}^2$ | A | 19162.84 |
| | | B | 6759.24 |
| | | C | 159.35 |
| | | D | 845.72 |
| YZ | $SPA_{YZ} = \frac{N}{n_Y \cdot n_Z}\sum_{i,j=1}^{i=n_Y;j=n_Z} E_{Y_i Z_j}^2$ | AB | 2272.16 |
| | | AC | 23.15 |
| | | AD | 311.01 |
| | | BC | 21.05 |
| | | BD | 126.03 |
| | | CD | 12.60 |
| Total | $SPA_T = \sum_{i=1}^{i=N}(R_i - R_{med})^2$ | | 29765.78 |
| | | | Calculated values [%] |
| Influence of Y to response | $\%Y = \frac{SPA_Y}{SPA_T}\cdot 100$ | A | 64.38 |
| | | B | 22.71 |
| | | C | 0.54 |
| | | D | 2.84 |
| Influence of interaction YZ to response | $\%YZ = \frac{SPA_{YZ}}{SPA_T}\cdot 100$ | AB | 7.63 |
| | | AC | 0.08 |
| | | AD | 1.04 |
| | | BC | 0.07 |
| | | BD | 0.42 |
| | | CD | 0.04 |
| | | Total % | 99.76 |

where:

- N represent the number of experiments (total numbers of results);
- $R_i$ the average values for experiment i;
- $R_{med}$ the average value for Ri;
- $n_A$ the number of levels of A factor. In this case the number of levels is 1 or 2.

On the basis of the values obtained in table 4, was obtained the percentages graph the influence of parameters and interactions between the parameters (figure 7).

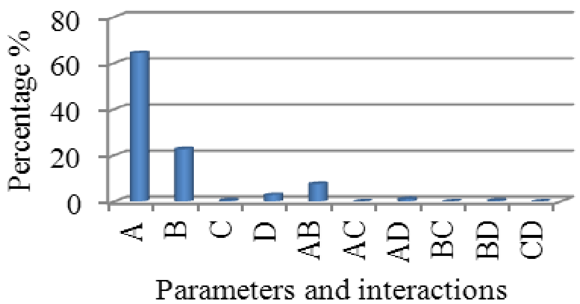


**Figure 7. The percentage of influence of parameters and their interactions**

## 4 CONCLUDING REMARKS

After applying Taguchi itinerary for calculating the percentage of influence of parameters and their interactions of the impact force, it is found that nozzle diameter D is the largest influence, with a percentage of 64.38%, followed by pressure p with a value of 22.71%. In third place is located interaction between nozzle diameter D and pressure p with a value of 7.63% and place 4 follows the impact angle ∝ with a value of 2.84%. The fifth place is located interaction between nozzle diameter D and the impact angle ∝ with a value of 1.04%.

The distance x and the other interactions influence the impact force with a percentage situated in the range of 0.54 % -0.04 %.

Notable, for the experimental domain, is that the distance x between the nozzle and the surface has an influence practically insignificant, with a value of only 0.54%.

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## 6 NOTATION

The following symbols are used in this paper:

D = nozzle diameter;
p = water pressure;
x = distance between the nozzle and impact surface;
α = impact angle (angle formed by the jet and impact surface).
$GL_f$ = degree of fredom