# Researches regarding influence of traverse speed and stand-off distance to the roughness in AWJ process

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**Abstract.** This paper aims to establish a relationship between surface roughness results from hydroabrasive processing and parameters with controlled variability, traverse speed and stand-off distance. Measuring the influence of these parameters is done using statistical and experimental tools. Establishing the relationship between the variation of input signals and the variation of result, is performed by introducing coefficients whose values determine the interdependence function between the input signal and response. Have been obtained diagrams of behavior of hydroabrasive process which allowed conclusions about the variability of the results obtained. Thus it can be concluded that the traverse speed and stand-off distance are input signals and they depends on the initial configuration of the system and its adjustment possibilities by variability of controlled parameters. Roughness is a result of this application, clearly defined which can be optimized by setting controlled parameters.

## 1 Introduction

Hydro-abrasive jet processing system is an open system with inputs set according to technical possibilities and outputs consisting of finished pieces with clear odds and technological conditions, with parameters of influence that can be controlled with variable parameters acting without control possibilities. All these elements are in a state of interdependence, changing of an element having predictable actions or not.

By changing the value of an element of influence we will get many possible outcomes that do not have a linear evolution. This is due to the effects that changing of the influence element value has on others, depending to it. Thus, for example, a finer granulation of abrasive does not necessarily achieve a best roughness (granulation abrasive influences mass flow, which can cause an increase in roughness) [1-2] or a higher pressure does not necessarily mean dimensional accuracy increased (increased pressure leads to accelerated aging, so a possible decrease in accuracy, etc). In Fig. 1 is shown the jet hydro-abrasive processing. Its optimization by using the method of robust design is achieved by applying criteria such as *Optimum = m (smaller, better)*, for roughness, and *Optimum = T (target achievement)* for dimensional accuracy.

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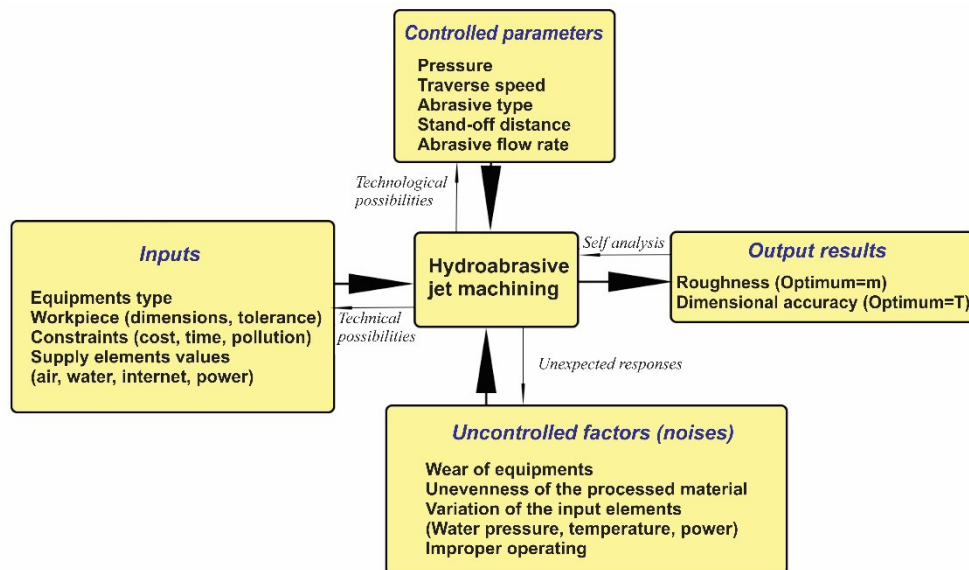
**Fig. 1.** Hydroabrasive jet processing – parametric diagram.

From the analysis of the presented diagram the dependence of the results, both for the system inputs and for the controlled and disruptive factors is observed. The controlled parameters image acts on the system as a whole. The elements of the respective matrix are strongly interrelated (quality feature does not increases or decreases linearly with each parameter), and the effects of random factors and inputs to the system are added to quantify the results [3, 4]

The factors that characterize jet hydro-abrasive processing are: external factors (abrasive material quality, hardness of the work piece, ambient temperature, environmental humidity, vibrations occurred during processing, variations in electric current, etc.), internal factors (wear of the nozzle, of the concentration tube, of the pump, etc.), processing factors (water pressure, processing speed, tube diameter, processing distance, cutting forces, etc.), human factors (operator experience, operator fatigue, etc.).

All these factors can be controlled, partially controlled or uncontrollable. Their management through a robust approach leads to optimization of technologic process by increasing its insensitivity to the effect of uncontrollable factors. Constance of results allows directing them to the intended target without damaging variability of target. Given that input elements have fixed values and noise factors can´t be controlled, it results that the choice of optimal configurations of controlled parameter values will decide the hydro-abrasive processing results.

The optimization criterion chosen (to *minimize* – in the case of roughness, or processing cost, to *maximize* if productivity aim is chosen, or to *achieve the target* if dimensional accuracy aim is chosen) is satisfied by choosing the optimal configuration of controlled factors values [5].

In the case of jet hydro-abrasive technological processing system, as main requirement appears the part´s drawing. This is accompanied by part´s quotas and tolerances (thickness, roughness, accuracy, etc.), the material´s properties (hardness, workability, material type, chemical structure, etc.). The part´s drawing is correlated with the parameters of jet processing facilities parameters, for the part be performed according to the requirements and possibilities of the machine.

Determining the execution possibility of the piece is followed by conditioning (other than those pursued as optimized result): production cost, execution time. Other input signals are constituted by elements of external supply of the hydro-abrasive processing system: pressure, temperature and water quality, values of tension and intensity of electricity supply, air supply pressure value.
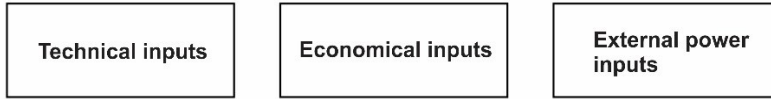
| Technical inputs | Economical inputs | External power inputs |

**Fig. 2.** Input signals in hydroabrasive jet system.

To the left of the scheme is shown the target to be reached (if the part can be executed) economic type inputs are positioned in the middle of the scheme (part execution must be economically justified) and to the right of the scheme are highlighted input values to the system related to system powering from external networks. Signals sent towards the hydro-abrasive jet technological processing system are of "technological requirement", "economic conditionality" and "feed values from the external network" type. The outputs from the system (work piece) must correspond to conditionings. A non-compliant output is an error (scrap). The multitude of not-compliant outputs is directly proportional to the variation of responses offered by the system. The objective of processing is to obtain a compliant result to initial conditionings.

## 2 Theoretical considerations

Optimization of hydro-abrasive jet process is to achieve the target proposed in accordance with the initial objective [target criterion if it is about a nominal quota proposed by the design or minimizing / maximizing criterion for the case of roughness, processing time, processing cost (minimizing) or profit (maximizing)] (Fig. 3).
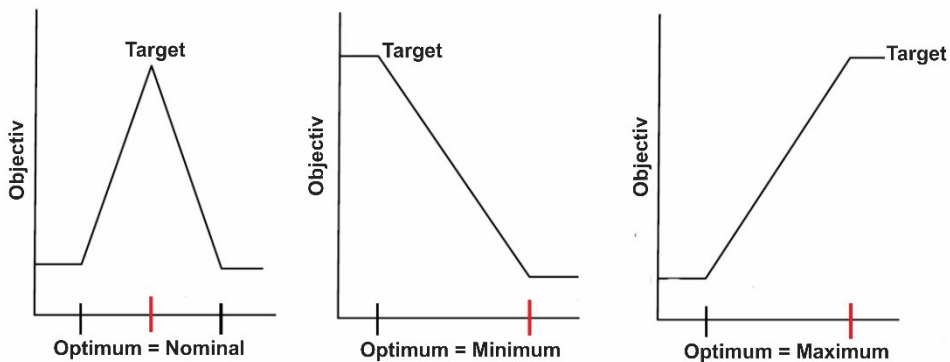


**Fig. 3.** Optimization of an open system based on defined objectives.

Reducing variation in responses of hydro-abrasive jet processing system is done by choosing operating parameters at which the system to respond consistently, regardless of randomly acting uncontrolled factors [6-7].

Technical and economical-type input values are conditionality in defining qualitative compliance being quantified within assessment process of responses, becoming optimized targets. System response to input values K, to control factors Pc, noise factors Z and interactions occurring I is noted by Y and has the form [8-9]:

$$Y = f\ (K, P_c, Z, I) \tag{1}$$

In the case of a technological process, Taguchi [10] conditions the acquisition of a response according to customer requirements by browsing three steps: selecting the system required for receipting the response; defining controlled parameters and choice of optimal level of thereof; identifying sources of noise and interactions that affect response (response tolerance).

Considering response Y as a desired result of the introduction in the system of input values and controlled factors, its variability is an undesirable outcome, caused by uncontrolled factors (noise) and unforeseen interactions occurred within the system between controlled factors. Relation (1) become:

$$Y = \alpha K + \beta P_c + [f(K, P_C, Z, I) - (\alpha K + \beta P_c)] \tag{2}$$

where: $(\alpha K + \beta P_c)$ is the signal received by the system to release the desired response; $[f(K, P_c, Z, I) - (\alpha K + \beta P_c)]$ is noise induced in the system by uncontrolled factors and interactions with unpredictable effects, occurring between controlled factors.

The existence of a large number of input signals leads to an enormous volume of calculations in assessing the final result. To reduce the volume of calculations the following rules are introduced:

1.  Input signals from of fixed type (material properties of the piece, values of power supply elements, certain parameters of the machine – axles number, machining precision) are considered to have zero influence on the outcome variability. Instead, the variability of these signals act on the result as an element of noise.

2.  Variable input signals, with the possibility of control, whose influence on the results is smaller than the louder noise influence, are considered negligible, being appreciated at their turn as noise [11].

Measuring the influence of each input signal is done by using statistical tools (regression analysis) and experimental tools. Establishing a relationship between the input signal variation and result variation represents how to measure the influence of that signal. An example of application relations cause - effect in the case of hydro-abrasive jet technological processing system can be seen in Fig. 4.
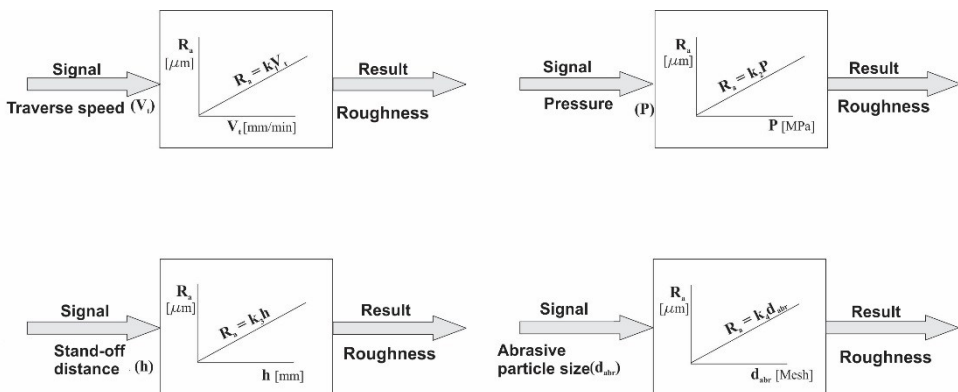


**Fig. 4.** Application of linear regression to some types of signals, who acting in the system of the technological process of hydroabrasive erosion, on the roughness of realized surfaces.

Applying equations (1) and (2) to the diagram shown in Fig. 4, wherein the response Y is exemplified as value of surface roughness $R_a$, and the configuration parameters are the speed of traverse $V_t$, the pressure P, the distance from focus tube h, and the abrasive particle diameter $d_{abr}$ there were obtained ideal dependence functions of the response $R_a$ and

each configuration parameter. Thus, for the relationship between roughness $R_a$ and traverse speed $V_t$ the ideal function is:

$$R_a = k_1 V_t \tag{3}$$

where $k_1$ is a coefficient that takes account of the value of traverse speed.

Also, the respone $R_a$ is influenced by other factors [12]:

$$R_a = f(V_t, P, h, d_{abr}) \tag{4}$$

If there are more parameters x, relation (4) can be written:

$$R_a = f(V_t, x_1, x_2, \ldots, x_n) \tag{5}$$

$$R_a = \gamma V_t + [f(V_t, x_1, x_2, \ldots, x_n) - \gamma V_t] \tag{6}$$

It follows that the first term $\gamma V_t$ it is the signal that lead to the answer $R_a$, and the second term, f $(V_t, x_1, x_2, \ldots x_n)$-$\gamma V_t$, is the noise who causes variability of response $R_a$.

## 3 Experimental results

Determination of the influence of the traverse speed on the roughness was carried out on samples of austenitic stainless steel X5CrNi 18-10 with following properties: Hardness Vickers, HV = 190; machinability, M = 80.8; modulus of elasticity, E = 200 GPa. Depth of cut was chosen $H_1 = 10$ mm, $H_2 = 20$ mm, $H_3 = 30$ mm. The input configuration is: pressure P = 345 MPa, type of garnet $d_{abr}$ = 80 Mesh, orifice diameter d = 0.28 mm, stand-off distance h = 1 mm, length of cut L = 100 mm. Traverse speed, $V_{t1} = 20$ mm/min, $V_{t2} = 30$ mm/min, $V_{t3} = 40$ mm/min, was determined based on the time and distance, modifying material thickness in processing setup in Maxiem Intelli-Max software version 23.0, from Maxiem 1530 equipment. The measurements of roughness was made at 2 mm of bottom of cut material and are shown in Table 1.

In classical method is calculated the average response for each factor and for each level. The calculated responses is shown in Table 1.

**Table 1**. Roughness values for different traverse speed and material thickness

| No. | Traverse speed [mm/min] | Material thickness [mm] | Roughness [μm] | | | | |
|-----|------------------------|------------------------|------|------|------|-----------------|--------|
| | | | **1** | **2** | **3** | **Arithmetic mean** | |
| 1. | 20 | 10 | 2.105 | 2.213 | 2.078 | 2.132 | 2.888 |
| 2. | | 20 | 2.964 | 3.251 | 3.187 | 3.134 | |
| 3. | | 30 | 3.340 | 3.642 | 3.219 | 3.400 | |
| 4. | 30 | 10 | 3.641 | 3.447 | 3.592 | 3.560 | 4.328 |
| 5. | | 20 | 4.155 | 4.409 | 4.273 | 4.279 | |
| 6. | | 30 | 5.261 | 4.903 | 5.271 | 5.145 | |
| 7. | 40 | 10 | 4.111 | 4.453 | 4.066 | 4.213 | 5.782 |
| 8. | | 20 | 5.827 | 6.081 | 5.767 | 5.891 | |
| 9. | | 30 | 7.402 | 7.045 | 7.281 | 7.242 | |

Applying equation (3) on the values obtained by experiment, are obtained for coefficient $k_1$, 3 values, respectively, $k_{11} = 0.144$; $k_{12} = 0.1442$; $k_{13} = 0.1445$

To determine the influence of stand-off distance on roughness were chosen the same basic configuration value, with a constant traverse speed for all samples, $V_t = 30$ mm/min.

Stand-off distance has following values $h_1 = 1$ mm; $h_2 = 2$ mm; $h_3 = 3$ mm. The results are shown in Table 2.

**Table 2.** Roughness values for different stand-off distance and material thickness

| No. | Stand-off distance [mm] | Material thickness [mm] | Roughness [μm] | | | | |
|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | Arithmetic mean | |
| 1. | 1 | 10 | 3.641 | 3.447 | 3.592 | 3.560 | 4.328 |
| 2. | | 20 | 4.155 | 4.409 | 4.273 | 4.279 | |
| 3. | | 30 | 5.261 | 4.903 | 5.271 | 5.145 | |
| 4. | 1.5 | 10 | 4.264 | 4.189 | 4.190 | 4.214 | 5.582 |
| 5. | | 20 | 5.910 | 5.812 | 5.673 | 5.798 | |
| 6. | | 30 | 6.705 | 6.589 | 6.911 | 6.735 | |
| 7. | 2 | 10 | 5.395 | 5.510 | 5.481 | 5.462 | 6.862 |
| 8. | | 20 | 6.895 | 7.012 | 7.141 | 7.016 | |
| 9. | | 30 | 8.262 | 8.093 | 7.969 | 8.108 | |

Applying equation (3) on the values obtained by experiment, according Fig.4, are obtained for coefficient $k_3$, 3 values, respectively $k_{31} = 4.328$; $k_{32} = 3.721$; $k_{33} = 3.431$.

## 4 Conclusions

The experiments shown in table 1 leads to the conclusion that traverse speed influences the roughness of processed surfaces, with increasing of traverse speed, increasing the roughness. For different thickness of material processed, are obtained different graphics of influence. (Fig.5). Coefficient $k_1$ still remains nearly constant. Based on experiments, optimal traverse speed, $V_{topt} = R_{aopt}/k_1$, can be fixed on the machine, using thickness variation to yield a required surface roughness.
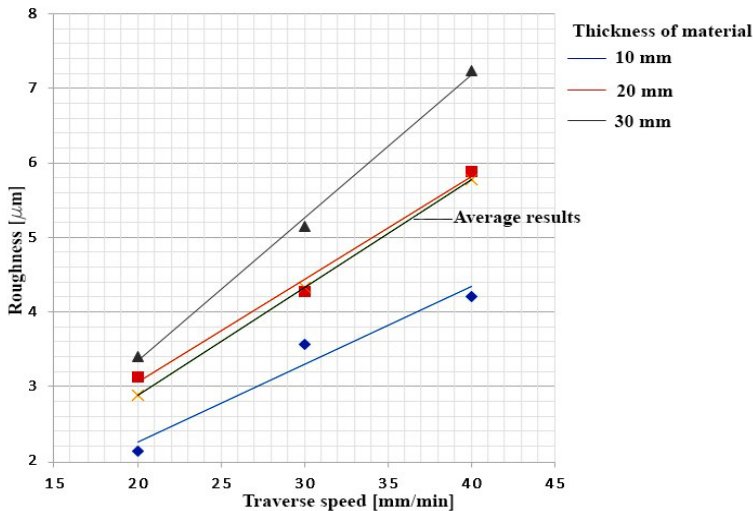


**Fig. 5.** Influence of traverse speed $V_t$, on roughness $R_a$ for different thickness of material.

Increased stand-off distance leads to increased roughness (Table 2). With the growth of stand-off distance, the hydro-abrasive jet loses the cutting energy, due to scattering of abrasive particles. The coefficient $k_3$ is not a constant coefficient, decreasing with growth of

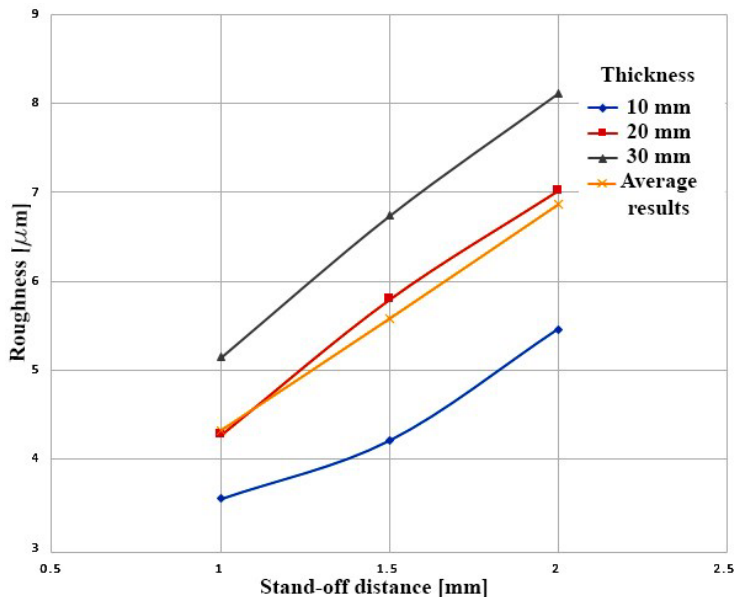thicness of material In Fig. 6 are shown graphs of influence of stand-off distance on roughness.



**Fig. 6.** Influence of stand-off distance h on roughness $R_a$ for different thickness of material.

This research opens the door to extensive research in this area, in order to optimize cutting abrasive water jet for different types of materials with variable thickness.

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