ISSN (Print) : 0974-6846
ISSN (Online) : 0974-5645
Indian Journal of Science and Technology, *Vol 10(17), DOI: 10.17485/ijst/2017/v10i17/112583, May 2017*

Condition Monitoring of Focusing Nozzle in Abrasive Water Jet Machine using Sound Sensor

R. Prabu[1] and A. Manivannan[2]

[1]Department of Mechanical Engineering, St. Joseph's College of Engineering, Old Mamallapuram Road, Semmencherry, Chennai – 600119, Tamil Nadu, India; Prabu.ravindran6@gmail.com
[2]Department of Mechanical, Krishnasamy College of Engineering and Technology, Nellikuppam Main Road, S. Kumarapuram, Cuddalore – 607109, Tamil Nadu, India; Manianbu91@gmail.com

Abstract

Objectives: The condition monitoring was done during the machining of Stainless Steel 316 Grade using a PCB microphone with a view to related the measured Sound Signal with the nozzle wear obtained. **Methods/Statistical Analysis:** It is done by using a Data Acquisition Device is used to connect the Computer with the microphone to analyze the signal using LAB VIEW Software. Also a Sensor signal conditioner is attached to the microphone to boost the sound signal. The machining is done by changing the abrasive flow rate and pressure parameters and the corresponding sound signal is recorded **Findings**: Regression analysis was carried out using Minitab 17 software and results showed that abrasive flow rate has more influence on nozzle wear rate. Regression equations were also developed for each nozzle hour based on process parameters. Also it was observed that the nozzle exit diameter increases with increase in nozzle life time. **Application/Improvements:** The future aspects are to develop a generalized equation for the nozzle wear rate based on the process parameters to develop a closed loop system.

Keywords: Monitoring, Nozzle Wear, Steel 316 Grade, Sound Signal

1. Introduction

1.1 Abrasive Water Jet Machining (AWJM)

Abrasive water jet machining is one of the oldest traditional machining processes which employs abrasive slurry, along with water is forced at high pressure through the nozzle, by high pressure pumps as shown in Figure 1. The high pressure abrasive water jet is capable of cutting soft materials like aluminum to hard materials like titanium, marble and sandwiched sheet metals. The generally used abrasive is garnet of different mesh size from 80 to 120 mesh size. The pressure varies from 100 to 2400 bar depending on the applications. The input process parameters are Abrasive water jet pressure, abrasive flow rate, traverse speed and standoff distance which are used to control the output process parameters such as surface finish, material removal rate, depth of cut, kerf width and kerf taper. The nozzle used in the machine has a mixing tube which is made of sapphire and the nozzle life varies from 100 – 150 hours.

*Author for correspondence

Figure 1. Abrasive water jet cutting machine.

2. Experimental Work

2.1 Microphone

Figure 2 shows the PCB 130 series of Array Microphones are pre polarized, condenser microphones coupled with ICP sensor powered preamplifiers and are thus referred to as ICP microphones. This eliminates the need to purchase a separate preamplifier. The 130 series microphones provide an extremely cost-effective method for large channel count sound pressure measurements. Typical applications include sound pressure mapping, acoustic mode analysis, near-field acoustic holography, and vibro-acoustic testing[4–6], along with other applications.

Figure 2. PCB microphone.

2.2 Data Acquisition System

Figure 3 shows the Data Acquisition system which is used to connect the LAB VIEW software with the microphone during the online monitoring process.

2.3 Signal Conditioner

Figure 4 shows the signal conditioner which is used to amplify the signal to increase the strength of the sound signal. The strength of the signal can be increased by using the Gain knob.

Figure 3. Data acquisition system.

Figure 4. Sound amplifier.

2.4 Work Piece

Figure 5 shows the work piece material Stainless steel SAE 316 Grade[7], on which machining is done. It is used for deck components of ships and construction purpose.

3. Experiment

The whole process is studied during the machining[8–11] of Stainless steel work piece as shown in Figure 6. Experiments are conducted based on the Orthogonal

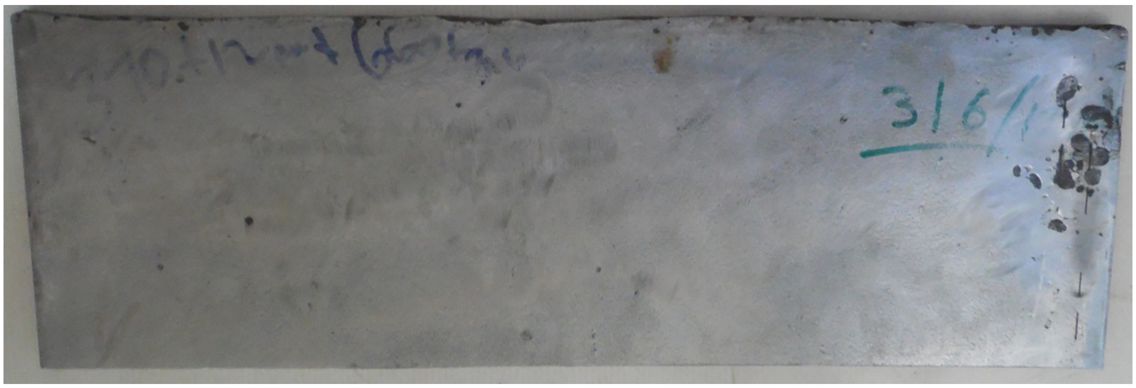

Figure 5. Stainless steel 316 grade before machining.

Figure 6. Work piece after machining.

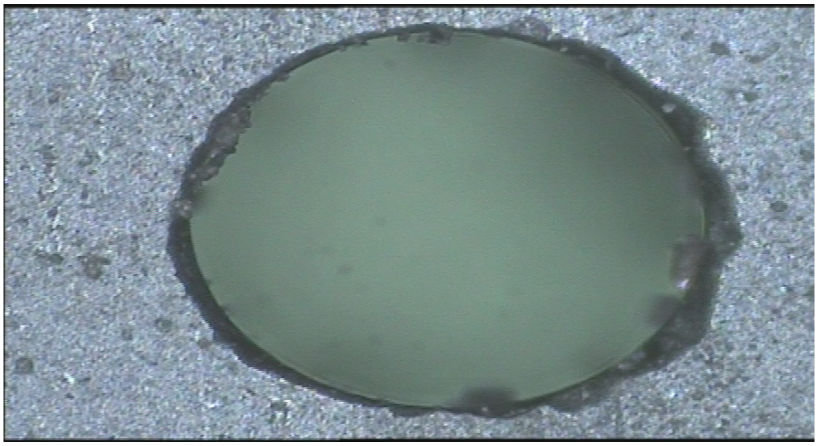

Figure 7. Magnified nozzle outlet portion.

Array (OA) generated using abrasive water jet process parameters during three different nozzle hours.

Figure 7 indicates the wearied bored diameter of the nozzle due to the interaction of the abrasives with the internal surface of the nozzle.

The below mentioned values for sound signal Root Means Square Value (RMS) are obtained by using the given water pressure and abrasive flow parameters. The sound signal obtained in terms of RMS (volts) is converted to decibels using the formula mentioned below. The conversion formula from RMS to decibel is as follows.

$$P = \frac{\textbf{RMS}}{\textbf{Sensitivity}} \quad (1)$$

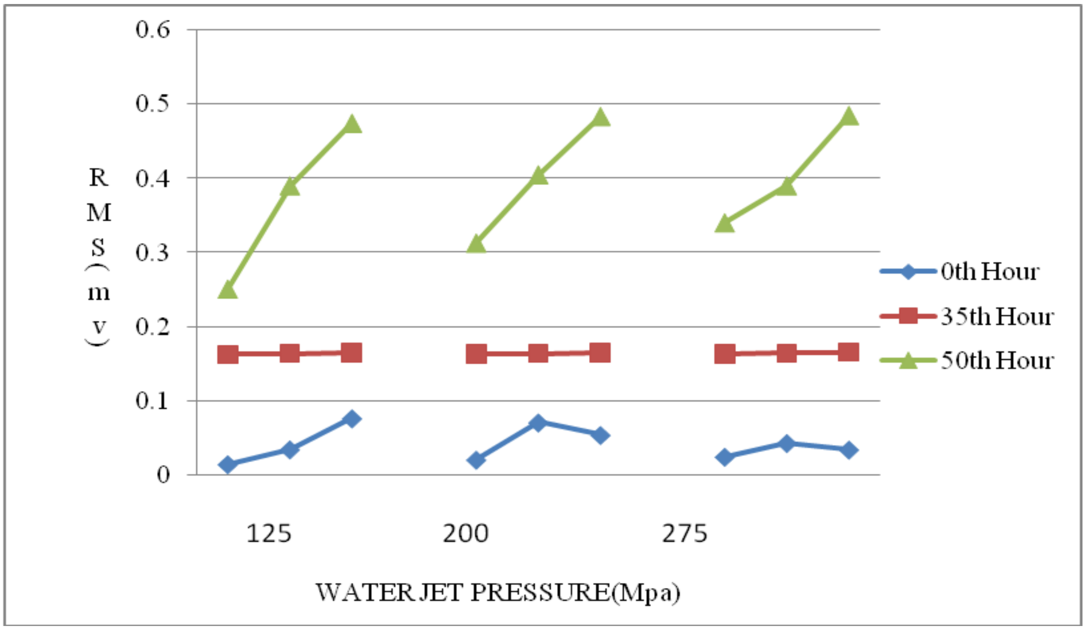

Figure 8. Graph for relation between RMS of sound and water jet pressure at different nozzle hours.

Table 1. Sound in decibels and RMS (Volts) for different nozzle hours at different parameter combination

Ex No.	Water pressure (Mpa)	Abrasive flow rate (gm/min)	RMS VALUE (Volts)			Sound (Decibels)		
			0 th Hour	35 th Hour	50 th Hour	0 th Hour	35 th Hour	50 th Hour
1	125	240	0.0141	0.1630	0.2506	83.997	105.256	108.991
2	125	340	0.0343	0.1640	0.3902	91.718	105.309	112.838
3	125	440	0.0767	0.1651	0.4748	98.708	105.367	114.542
4	200	240	0.0202	0.1632	0.3128	87.119	105.266	110.917
5	200	340	0.071	0.1641	0.4051	98.037	105.314	113.163
6	200	440	0.054	0.1655	0.4841	95.66	105.388	114.710
7	275	240	0.0243	0.1634	0.3402	88.616	105.277	111.647
8	275	340	0.043	0.1647	0.3902	93.681	105.346	112.838
9	275	440	0.0340	0.1657	0.4854	91.6488	105.398	114.734

P = Pressure in Pascal's (Pa) & Voltage is the preamps output peak voltage.

$$\text{Sensitivity} = \text{db} = 20\log\left(\frac{P}{P0}\right) \qquad (2)$$

P = Pressure in Pascal's (44.5 mv/pa)

Experimental results are tabulated for Sound signal at different nozzle hour by varying water jet pressure (MPa) and abrasive flow rate (gm/min) in the below combinations.

Table 1 show how the process parameters Pressure and Abrasive flow rate influence the Sound signal expressed in terms of RMS also in terms of decibels.

The graph is plotted for RMS vs. Water jet pressure by varying abrasive flow rate at different nozzle hours as shown in Figure 8. The graph clearly indicates that RMS value increases with increase in nozzle hour. Another

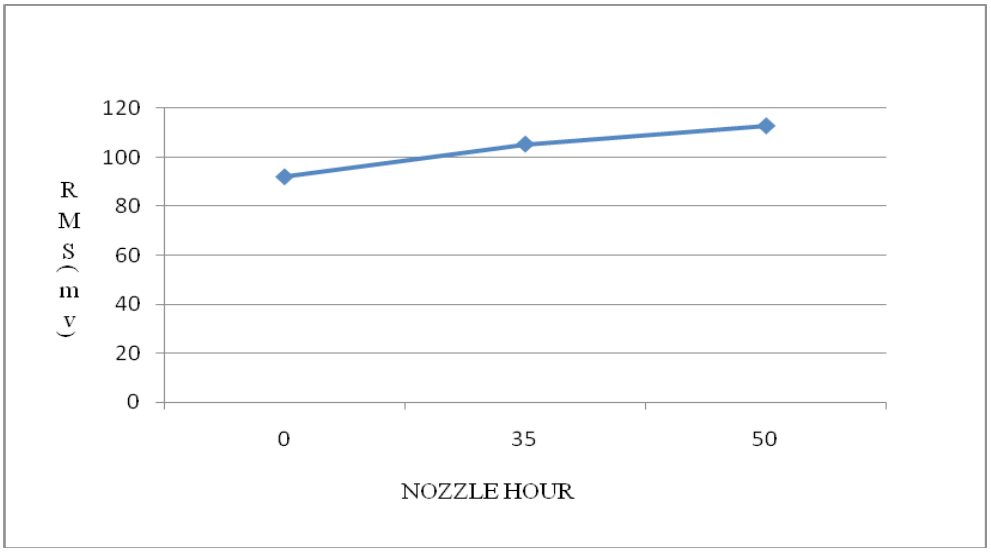

Figure 9. Linear increase in RMS at different nozzle hours.

graph is also plotted for Nozzle exit diameter vs. Nozzle hour as shown in Figure 9. From the Figure 9 it is clear that nozzle exit diameter increases with increase in nozzle hour.

The graph is plotted for RMS vs. Nozzle hour. And from the graph it is clear that RMS increases with increase in Nozzle hour.

4. Optimization

Optimization algorithms are becoming increasingly popular in engineering activities, primarily because of the availability and affordability of high-speed computers. They are extensively used in those engineering problems where the emphasis is on maximizing or minimizing of a certain goal. Taguchi analysis is used for optimization process.

4.1 Taguchi Design of Experiments

The working ranges of the parameters for subsequent design of experiment, based on Taguchi's L9 OA design have been selected. In the present experimental study, spindle speed, feed rate and depth of cut have been considered as process variables as shown in Table 2.

Table 2. Parameters and their levels

Parameter	Level 1	Level 2	Level 3
Pressure	125	200	275
Abrasive Mass flow Rate	240	340	440

5. Results and Discussions

5.1 Regression Analysis

It is a type of analysis which is used to find the relation between known and unknown variables. It is better to say the relationship between controllable and uncontrollable variables. The regression analysis plots graphs between the two variables based on the number of trials performed. A generalized equation is generated which hold well up to certain extent, which gives the value of unknown variable with the value of known variables. Here the regression analysis is carried out with the help of Minitab – 17 software.

5.1.1 Regression Analysis: RMS vs. Pressure, Abrasive for 0th Hour

Analysis of Variance
Model Summary
Regression Equation
RMS 0 = -0.0230 - 0.000053 Pressure + 0.000220 Abrasive

The regression equation was obtained for the fresh nozzle at 0th hour. It is clear that R-Sq value is well above 70% as shown in Table 3 which means that the equation holds good .Also the P Value in Table 3 is well between 0-1 which also adds that the relation obtain is true.

Table 3 (a). F value and P value for 0th hour nozzle

Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Regression	2	0.003003	0.001501	10.32	0.011
Pressure	1	0.000094	0.000094	0.65	0.451
Abrasive	1	0.002908	0.002908	19.99	0.004
Error	6	0.000873	0.000145		
Total	8	0.003876			

Table 3 (b). R-sq(adj) and R-sq(pred) values for 0th hour nozzle

S	R-sq	R-sq(adj)	R-sq(pred)
0.0120621	77.48%	69.97%	41.78%

5.1.2 DRegression Analysis: RMS vs. Pressure, Abrasive for 35th Hour

Analysis of Variance

Model Summary

Regression Equation

RMS 35 = 0.159748 + 0.000004 Pressure + 0.000011 Abrasive

The regression equation was obtained for the nozzle at 35th hour. It is clear that R-Sq value is well above 70% as shown in Table 4 which means that the equation holds good .Also the P Value in Table 4 is well between 0-1 which also adds that the relation obtain is true.

5.1.3 DRegression Analysis: RMS vs. Pressure, Abrasive for 50th Hour

Analysis of Variance

Model Summary

Regression Equation

RMS 50 = 0.0417 + 0.000223 Pressure + 0.000901 Abrasive

The regression equation was obtained for the nozzle at 50th hour. It is clear that R-Sq value is well above 70% as shown in Table 5 which means that the equation holds

Table 4 (a). F value and P value for 35th hour nozzle

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	2	0.000008	0.000004	311.61	
Pressure	1	0.000000	0.000000	37.70	0.000
Abrasive	1	0.000007	0.000007	585.52	0.000
Error	6	0.000000	0.000000		
Total	8	0.000008			

Table 4 (b). R-sq(adj) and R-sq(pred) values for 35th hour nozzle

S	R-sq	R-sq(adj)	R-sq(pred)
0.0001130	99.05%	98.73%	98.24%

Table 5 (a). F value and P value for 50th hour nozzle

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	2	0.050399	54.25	0.000	
Pressure	1	0.001673	0.001673	3.60	0.106
Abrasive	1	0.048726	0.048726	104.90	0.000
Error	6	0.002787	0.000465		
Total	8	0.053186			

Table 5 (b). R-sq(adj) and R-sq(pred) values for 50th hour nozzle

S	R-sq	R-sq(adj)	R-sq(pred)
0.0215526	94.76%	93.01%	85.29%

good .Also the P Value in Table 5 is well between 0-1 which also adds that the relation obtain is true.

5.2 Taguchi Analysis: RMS 0, RMS 35, RMS 50 versus Pressure, Abrasive

Taguchi analysis was carried out using Minitab 17 software and the following results were obtained from the model.

5.3 Linear Model Analysis: SN Ratios versus Pressure, Abrasive

Response Table for Signal to Noise Ratios obtained from Minitab 17 software

Condition: Smaller is better

It is very clear from the Table 6 the abrasive flow rate process parameter has Rank 1 which implies that it has more effect on the nozzle wear rate.

Table 6. Parameter ranking

Level	Pressure	Abrasive
1	12.70	14.09
2	12.07	12.10
3	11.99	10.57
Delta	0.71	3.53
Rank	2	1

5.4 Main Effects Plot for S/N Ratios

Figure 10 shows that the pressure and abrasive flow parameters S/N ratio decreases with increase in levels. Also it is clear that for pressure parameter 200 MPa is near the mean line. And in abrasive flow parameter 340 gm/min is near the mean line. This two parameter combination show best result for obtaining minimum sound signal.

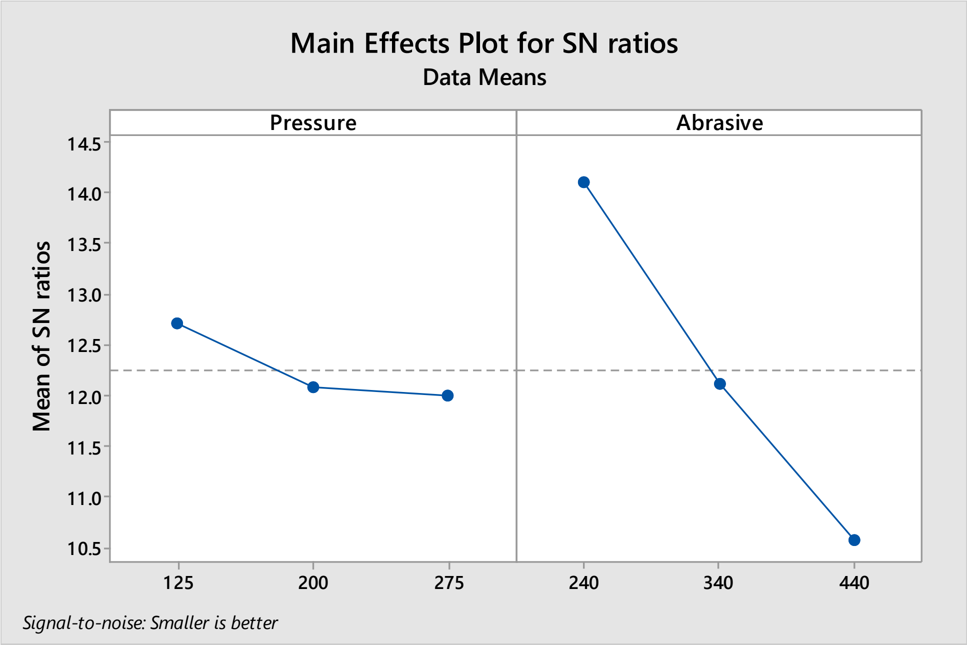

Figure 10. S/N ratio for water jet pressure and abrasive flow rate parameters for different nozzle hours.

6. Conclusion

From the experimental results and optimization results from software the following observations are made:

- The nozzle wears (nozzle exit diameter) increases with increase in nozzle hour.
- The RMS value of the sound signal also increases with increase in nozzle hour.
- Regression equation for RMS Values for different nozzle hour has been generated.
- The Pressure parameter of 200 MPa and abrasive flow rate of 340 gm/min is the best combination for reducing the nozzle wear rate.
- Also the maximum allowable sound level for nozzle wear rate is up to 110 db.

7. References

1. Verma S, Moulick SK, Mishra SK. Nozzle wear parameter in water jet machining: the review. International Journal of Engineering Development and Research (IJEDR). 2014; 2(1):1063–73 .
2. Nanduri M, Taggart DG, Kim TJ. The effects of system and geometric parameters on abrasive water jet nozzle wear. International Journal of Machine Tools and Manufacture. 2002 Apr; 42(5):615–23 . CrossRef.
3. Baralic J, Nedic B, Marusic V. Focusing tube wear and quality of the machined surface of the abrasive water jet machining. Tribology in Industry. 2008; 30(3–4):55 .
4. Kovacevic R, Wang L, Zharng YM. Identification of abrasive water jet nozzle wear based on parametric spectrum estimation of acoustic signal. In the Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture. 1994 Aug 1; 208(3):173–81.
5. Valicek J, Hloch S. Using the acoustic sound pressure level for quality prediction of Surfaces created by abrasive water jet. The International Journal of Advanced Manufacturing Technology. 2010 Apr; 48(1):193–203. CrossRef.
6. Hreha P, Radvanska A, Carach J, Lehocka D, Monkova K, Krolczyk G, Ruggiero A, Samardzic I, Kozak D, Hloch S. Monitoring of focusing tube wear during Abrasive Water Jet (AWJ) cutting of AISI 309. METALURGIJA. 2014; 53(4):533–6.
7. Jurisevic B, Brissaud D, Junkar M. Monitoring of Abrasive Water Jet (AWJ) cutting using sound detection. The International Journal of Advanced Manufacturing Technology. 2004 Nov; 24(9):733–7. CrossRef.
8. Selvan MCP, Raju NMS. A machinability study of stainless steel using abrasive water jet cutting technology. International Conference on Mechanical, Automobile and Robotics Engineering (ICMAR) Penang, Malaysia; 2012. p. 208–12.
9. Begic-Hajdarevic D, Cekic A, Mehmedovic M, Djelmic A. Experimental study on surface roughness in abrasive water jet cutting. 25th DAAAM International Symposium on Intelligent Manufacturing and Automation; 2014. p. 394–9.
10. Gok A, Gologlu C, Demirci IH, Kurt M. Determination of surface qualities on inclined surface machining with acoustic sound pressure. Strojniski vestnik - Journal of Mechanical Engineering. 2012 Jun 29; 58(10):587–97. DOI:10.5545/sv-jme.2012.352. CrossRef.
11. Sharma A, Lalwani DI. Experimental investigation process parameters influence on surface roughness in abrasive water jet machining of AISI H13 die steel. In the Proceedings of Conference on Intelligent Robotics, Automation and Manufacturing; 2013 Dec.