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Design and Fabrication of Abrasive Jet Machine (AJM)

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Abrasive Jet Machining (AJM) is the process of material removal from a work piece by the application of a high-speed stream of abrasive particles carried in a gas or air medium from a nozzle. The material removal process is mainly by erosion. The AJM will chiefly be used to cut shapes in hard and brittle materials like glass, ceramics etc. the machine will be automated to have 3 axes travel. The different components of AJM are Compressor, Vibrator, dehumidifier, Pressure Regulator, and Dust filter, Nozzle, Pressure gauge etc. The different components are selected after appropriate design calculations. In paper contains the Abrasive Jet Machine design and fabrication by using available hardware and software etc. taking into consideration of commercially available components. Care has been taken to use less fabricated components rather than directly procuring them, because, the lack of accuracy in fabricated components would lead to a diminished performance of the machine.

Keywords: machining process, NTD, MRR, abrasive particles.

1. Introduction

1.1. *Abrasive Jet Machining principle*

Abrasive Jet Machining (AJM) is the removal of material from a work piece by the application of a high-speed stream of abrasive particles carried in gas medium from a nozzle. The AJM process is different from conventional sand blasting by the way that the abrasive is much finer and the process parameters and cutting action are both carefully regulated. The process is used chiefly to cut intricate shapes in hard and brittle materials which are sensitive to heat and have a tendency to chip easily. The process is also used for drilling, de-burring and cleaning operations [1, 2]. AJM is fundamentally free from chatter and vibration problems due to absence of physical tool [3, 4]. The cutting action is cool because the carrier gas itself serves as a coolant and takes away the heat [5].

1.2. *Variables affecting performance*

The major variables affecting the performance parameters like material removal rate, machining accuracy etc. are as follows:

1. Composition of carrier gas
2. Types of abrasive
3. Size of abrasive grain
4. Velocity of abrasive jet
5. Flow rate of abrasive jet
6. Work piece material
7. Geometry, composition and material of nozzle
8. Nozzle tip distance (stand-off distance)
9. Mixing ratio
10. Impingement angle

1.3. *Characteristics of different variables*

1.4. *Operating characteristics*

The main performance measuring parameters of AJM are as follows:

1. The material removal rate in gm/mm^3
2. The accuracy and surface finish of the machined surface
3. The nozzle wear rate

Table 1 Different variable parameters [6]

Medium	Air, CO2, N2
Abrasive	SiC, Al2O3 (of size 90-150 microns)
Flow rate of abrasive	3 to 20 gram/min
Velocity	150-300 m/min
Pressure	2-8 kg/cm^2
Nozzle size	0.07-0.40 mm
Material of nozzle	C60, sapphire
Nozzle life	12-300 hrs
Standoff Distance	0.25-15 mm (8 mm generally)
Work material	Non-metals like glass, ceramics, granites Metals & alloys of hard materials like germanium, silicon etc.
Part application	Drilling, cutting, deburring, etching, cleaning

The Abrasive Jet Machine reveals that the machining process was started a few decades ago. Till date there has been a complete and detailed experiment and theoretical study on this process. Most of the studies argue over the hydrodynamic characteristics of abrasive jets, hence determining the influence of all operational variables on the process usefulness including abrasive size, kinds and concentration, impact speed and angle of strike [30 to 32]. Other papers found new problems concerning carrier gas typologies, nozzle shape, size and wear rate, jet velocity and pressure, stand-off distance (SOD). These papers state the overall process performance in terms of material removal rate(MRR), geometrical tolerances and surface finish of work pieces, as well as in terms of nozzle wear rate or nozzle life. Finally, there are several significant and important papers which focus on either leading process mechanisms in machining of both ductile and brittle materials, or on the development of systematic experimental-statistical approaches and artificial neural networks to predict the relationship between the settings of operational variables and the machining rate and accuracy in surface finishing [33, 34]. The machining process produces no heat and hence changes in microstructure or strength of the surface is less likely to occur. The air itself acts as a coolant and hence AJM process is regarded as damage free micromachining method [7, 8]. The fracture toughness and hardness of the target materials are critical parameters affecting the material removal rate in AJM. However, their effect on the machinability varied greatly with the employed abrasives particles [9, 10].

In recent years abrasive jet machining has been gaining increasing acceptability for debarring applications. The influence of abrasive jet de-burring process parameters is not known clearly. AJM de-burring has the advantage over manual de-burring method that generates edge radius automatically [35]. This increases the quality of the de-burred components. The burr removal process and the generation of a convex edge vary as a function of the parameters like jet height and impingement angle, when SOD is fixed. The effect of other parameters, such as nozzle pressure, mixing ratio and abrasive size are less significant [11, 12].

In integration manufacturing technology abrasive jet finishing combined with grinding gives rise to a precision finishing process, in which slurry of abrasive and liquid solvent is introduced to grinding area between wheel and work surface under no radial feed [1]. The particles are driven and energized by the rotating grinding wheel and liquid pressure and increased slurry speed between grinding wheel and work surface accomplishes micro removal finishing. The study of the results of machining under various operating conditions approves that a commercial AJM machine was used, with nozzles hiving diameter ranging from 0.45 to 0.65 mm, the nozzle materials being either tungsten carbide or sapphire, which have high tool lives. SIC and aluminum oxides were the two abrasives used [2]. Other parameters studied were standoff distance (5–10 mm), spray angles (60° and 90°) and pressures (5 and 7 bars) for materials like ceramics, glass, and electro-discharge machined (EDM) die steel. The holes drilled by AJM may not be circular and cylindrical but almost elliptical and bell mouthed in shape. High material removal rate conditions may not necessarily r small narrow clean-cut machined areas [28,29].

Studies show that AJM is a good micro-machining method for ceramics. The machinability during the AJM process can be associated to that given by the established models of solid particle erosion, in which the material removal is assumed to initiate in the ideal crack formation system. However, it was explained that the erosion models are not applicable to the AJM test results, because the relative hardness of the abrasive particles against the target material, which is not taken into account in the models, is important in the micro-machining process [26 to 31]. No degradation in strength took place for the AJM ceramic surfaces. This is attributed to the fact that radial cracks did not propagate downwards by impacts during the machining process [3].

Quality of the surface produced during abrasive water jet machining of aluminium has been investigated in recent years. The abrasive used was garnet of mesh size 80. The variables were stand-off distance (SOD) of the nozzle from the work piece surface; feed rate and jet pressure [25-29]. The evaluating criteria width of cut, taper of the cut slot and work surface roughness. It was found that in order to reduce the width of cut; the nozzle should be placed close to the work piece surface. Increase in jet pressure effects in widening of the cut both at the top and at exit of the jet from the work piece [4].

2. Materials and methods

2.1. *Nozzle*

AJM nozzle is usually made of tungsten carbide or sapphire (usually life – 300 hours for sapphire, 20 to 30 hours for WC) which has resistance to wear. The nozzle is made of either circular or rectangular cross section and head can be head can be straight, or at a right angle [26-32]. It is so designed that loss of pressure due to the bends, friction etc. is minimum possible.

With increase in wear of a nozzle, the divergence of jet stream increases resulting in more stray cutting and high inaccuracy [13, 14].

2.2. *Principle of operation*

1. Cutting (Hack-saw)
2. Facing
3. Turning
4. Drilling (Guide Drill - 6.0 mm, Drill bit - 8.5 mm, 10.2 mm)
5. Threading (M-12*1.75- Tap, Diameter)
6. Filling
7. Tapping

Figure 1 Abrasive nozzle operation

2.3. *Mixing chamber*

The high-pressure air from the compressor is passed through a FRL unit to remove any impurities. Then it is fed to the abrasive chamber which has one inlet for the incoming compressed air and outlet for mixture of abrasive particles and air. The abrasive particles are introduced from the side so to form a cyclone to facilitate better mixing. The chamber is of cylindrical shape made up of mild steel [30-32].

2.4. *Piping systems*

The piping systems are required for carrying the compressed air from the compressor to the mixing chamber and from the mixing chamber to the nozzle orifice via the filter regulator. It is required to maintain the pressure in the line without eroding the pipe. Here nylon braided hoses having 12 mm internal dia is provided [28-35]. This is used because of long life, light weight, durability and easy availability. Also the head loss is very small when it occurs a bend. The hose is composed of reinforcement of synthetic yarn in between two or more layers of soft PVC. The yarn is reinforced in longitudinal directions as well as crosswise so as to increase the strength [15, 16].

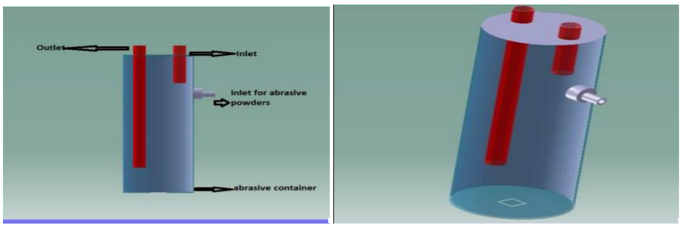

Figure 2 Mixing chamber in CATIA model

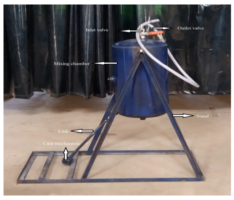

Figure 3 Mixing chamber in fabricated model

Figure 4 Braided hose pipe structure

2.5. *Dehumidifier*

Dehumidifier is necessary for filtering the air and regulating the pressure. The common impurities suspended in the compressed air are dust particles of various sizes, moisture, and oil particles. Excess moisture present in the pipeline may result in coagulation of particles and jam the nozzle opening. Air filters have a porous membrane having various pores sizes like 5, 10, or 15 μm. They block the particles larger than the pores [17].

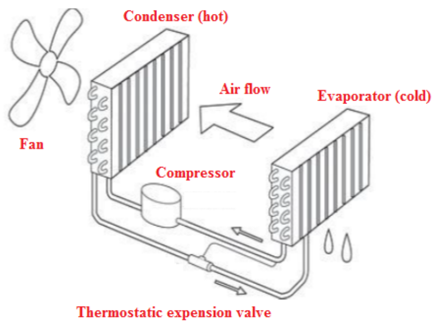

Figure 5 Dehumidifier

2.6. *Pressure regulator*

The line pressure is regulated by pressure regulator. A pressure regulator has a restricting element, a loading element, and a measuring element. The restricting element is a type of valve [21-28]. It can be a butterfly, valve globe valve, poppet valve, or any other type of valve that is capable of operating as a variable restriction to the flow. The loading element applies force to the restricting element. It can be a simple weight, a spring, a piston actuator, a diaphragm actuator in combination with a spring [18, 19].

2.7. *Air compressor*

Air compressors compress the air to high pressure taking input energy from electric motor or internal combustion engine. In abrasive jet machining high pressure air jet is required so that the suspended particles in it can strike the work piece at high velocity. Positive displacement air compressors work by forcing air into a chamber whose volume is reduced to compress the air. Piston type compressors use this principle by pumping air into an air chamber through the use of the motion of pistons. They use one-way valves to direct air into a chamber, where the air is compressed [20].

2.8. *Vibrating unit*

Vibrating Unit is used for mixing the air with the abrasive particles (Al_2O_3). The Abrasive particles are stored in a container through which air is flown. The particles are agitated by means of a cam and motor arrangement [21]. The rotation of cam results in vibration in the abrasive container. The flow rate of abrasive materials can be controlled by manipulating the rotational speed of the motor. The abrasive container will have one inlet and one outlet for air passage and will be vertically suspended from a hinged joint [26, 27].

So, the vibrating unit consists of following parts:

1. Motor (Induction type).
2. Cam.

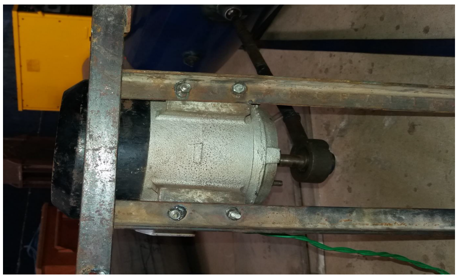

Figure 6 Vibrating unit

2.9. *Abrasives*

Aluminum oxide (Al2O3) Silicon carbide (SiC) Glass beads, crushed glass and sodium bicarbonate is some of abrasives used in AJM. Selection of abrasives depends on MRR, type of work material, machining accuracy [22 to 25].

Table 2 Types of abrasives [8, 35]

Abrasives	Grain Sizes	Application
Aluminum oxide (Al_2O_3)	12, 20, 50 microns	Good for cleaning, cutting and debarring
Silicon carbide (SiC)	25, 40 microns	Used for similar application but for hard material
Glass beads	0.635 to 1.27 mm	Gives matte finish
Dolomite	200 mesh	Etching and polishing
Sodium bi carbonate	27 micros	Cleaning, debarring, and cutting of soft material Light finishing below 50°C

2.10. *Machining chamber*

This chamber is used for machining the work piece material and prevent blow of abrasive particles around the surrounding.

Figure 7 Machining chamber

3. Design and fabrication

3.1. *Design of nozzle*

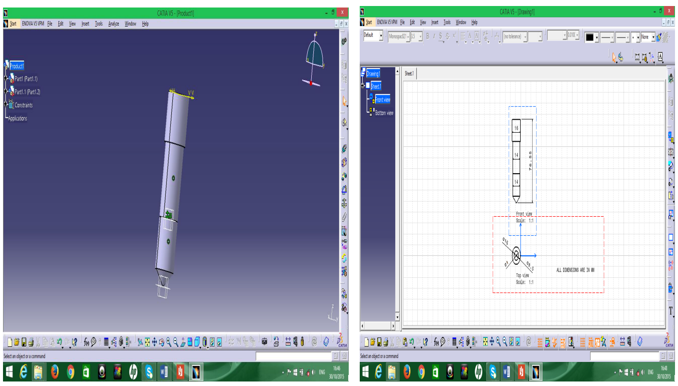

Figure 8 Nozzle design model in CATIA

3.2. *Fabrication model*

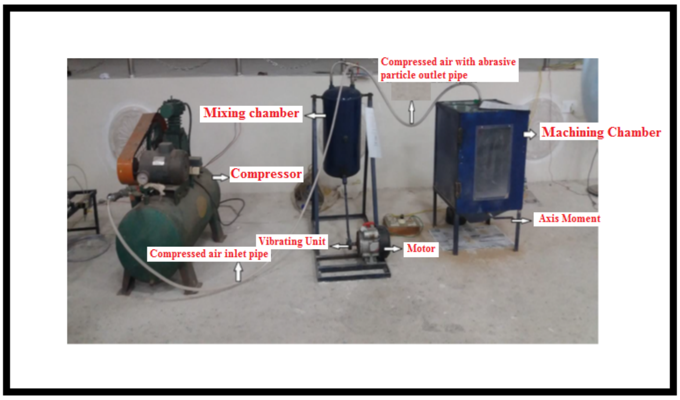

Figure 9 Final fabricated model of AJM

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4. Conclusion

1. This paper contains the complete design of the low-cost Abrasive Jet Machine.
2. The total assembly is designed taking in account of currently available components in the market.
3. This fabricated model can go beyond its current position and capabilities by employing automation into it.
4. This can be done by using stepper motors or DC servo motors interfaced with standard PCI controllers or standalone controllers.
5. The 2-D profiles can be converted into standard G-codes and M-codes and that can be sent to the machine to perform automated machining.

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