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Implementation of the Non-Conventional Machining Technology "The Cavitation Process

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Abstract--This paper introduces and presents a new method of non-conventional machining by using the cavitation process. This method can be called "Cavitation Machining (CM)". The proposed methodology on the development of Non-conventional/Non-traditional machining (NTM) by Cavitation Machining is presented and finally, conclusion and future research direction are provided. The necessity of precise and accurate parts without any surface effects in different manufacturing industries has led to a revolution in machining craft. The Non-conventional machining (NCM) is widely utilized in responding to modern industrial problems. Two kinds of cavitation machining (CM) are presented: Hydrodynamic Cavitation Machining (HCM), and Ultrasonic Cavitation Machining (UCM), they will be introduced, and the parameters associated with them will be presented.

Keywords: Non-conventional Machining (NCM), Cavitation machining (CM), Ultrasonic, Abrasive particle,Hydrodynamic Cavitation Machining (HCM), Non-traditional machining (NTM)

I. INTRODUCTION

In Conventional machining processes the materials are removed from the work- piecesurface, in the form of chips. Thus, it is difficult to achieve high degree of precision and accuracy. Taguchi mentioned that high precision and accuracy cannot be achieved by using theconventional machining processes where the material is removed in the form of chips. Additionally, due to the applied force work-piece surface can be damage and the reasonable poor surface finish is obtained [13], [1]. In many cases, engineering materials cannot be machined by using the traditional machining processes, because of many factors of materials like their shape, geometry etc. [3]. In Non-traditional machining (NTM) processes the material is removed in the form of atoms or molecules, individually or in groups. In addition, to this low forces are applied who preventthe work piece and surface from damage, so required accuracy can be achieved [13]. NTM processes are classified into main four categories according to the type of energy used in material removal: chemical, electro-chemical, mechanical and thermal [7]. Chemical machining (CHM), Electrical discharge machining (EDM), electro chemical machining (ECM), laser beam machining (LBM),ultrasonic machining (USM), and abrasive/water jet machining (AWJM) are some types of NTM processes [1].'**Cavitation**' is known as a repeated formation and forceful collapse of bubbles in a liquid, which produces very large hydrodynamic stresses. These bubbles can be either gas or vapor filled and can occur in a variety of liquids under a wide range of operating conditions. The collapse of a spherical bubble causes the source of an impacting micro jet. This leads to rising local high pressures and shears. The magnitude of pressure pulse may be as high as 10^3 MPa. The implosion of the bubbles can remove small particles from the surface. This is called cavitation erosion. Cavitation decreases the performance of the hydraulic system, and induces noise and vibration that are undesirable [6]-[8].Cavitation erosion is a complex phenomenon that involves the interaction of hydrodynamic, mechanical, metallurgical and chemical factors. It is a major concern in the hydropower generation industry, but cavitation has been exploited in useful spheres like, in ultrasonic cleaner, in promoting chemical reactions, and in biological and medicinal fields [8], [9]. Cavitation leads to erosion in hydraulic systems, but in comparison with the time of machining processes, the time of erosion is too long. Using an appropriate proportion of abrasive particles in hydraulic liquid can reduce the time of erosion. Hence, a work-piece can be machined in a micro dimension using the Cavitation Machining (CM) process. In the next section relevant literature on Non-traditional machining (NTM) processes and cavitation are reviewed.

II. LITERATURE REVIEW

A. Non-Conventional Machining (NCM) Processes

The use of these NCM processes is becoming increasingly inevitable and popular on the new age. The demand for micro and Nano-machining has made such processes more significant in the present day manufacturing environment [13]. In EDM the basic process is carried out by producing controlled electric sparks between a tool (electrode) and the work piece, both of which are immersed in a dielectric fluid. In this process, both of tool and the work piece should beconductive of electricity [5],[2].The ultrasonic machining

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(USM) process is effectively used to machining conductive and non-conductive materials. Its material-removal mechanism includes impacting and hammering. The USM is effective and particular for all brittle materials [6], [2].In ECM process the material dissolution occurs when the work piece is made an anode in an electrolytic cell. The cathode tool is separated from the anode by a narrow electrolytic spacing through which electrolyte flows with high velocity. This process is for the materials which are conductive of electricity [7], [2].In the above processes, the shape of work piece follows of the shape of tool. There are several NTM processes as discussed in [2]. Each of NTM processes is associated with advantages and disadvantages that lead to its particular application [2].

B. Cavitation Process

As the above discussion, in cavitation process, the amplitude of pressure pulses is high (more than 1GPa), and it is also characterized by short duration (about 1 ns to µs). Because of very small dimension of implosion zones (10^{-5}m)and fast rise of pressure, the estimation of actualpressures during implosion is very difficult. Former researches show that the density of energy flux, supplied to the material by imploding cavitation bubbles in a unit of time, can be assumed proportional to the following equation:

$$J = \frac{1}{T}\frac{1}{2\sigma C}\sum_{K}^{N} n_K P_K^2 \qquad \text{.................................. (1)}$$

Where T is the sampling period duration, σ the density, C the sound celerity of liquid, N is the number of pressure intervals, n_K the number of pulses measured by means of a pressure sensor in a single interval, P_k the value of pressure amplitude corresponding to each single interval midpoint, K the consecutive number of the interval [10], [4].There are a lot of parameters affecting the erosion in cavitation. Alicja Krella [11] founded that erosion is exponentially dependent on the energy supplied to the material (J) by imploding cavitation bubbles; hence, every parameter affecting J should be considered as an important factor in cavitation erosion. These parameters and the mentioned parameters in equation (1) are the same. In this equation, the most important factor is density which relates to the liquid type. Cavitation erosion can increase by employing a liquid with lower density. AlicjaKrella[11] also mentioned that there is a threshold value of cavitation energy flux density (J) = 10mW/m^2, below which no significant erosion can be identified even after 16 h of exposure because of the insufficient cavitation.

Employing parameters should be in a way in which the amount of (J) is more than 10mW/m^2. Another important factor is cavitation number uses in hydrodynamic cavitation. It can be defined as follows:

$$\sigma = \frac{P - P_V}{\rho V^2 / 2} \qquad \text{.................................. (2)}$$

Where P is the pressure at a reference point in the flow, Pv is the Vapor pressure of the liquid at the reference temperature, ρ is the liquid density and V is the characteristic velocity at the reference point.Decreasing the cavitation number, results in higher probability in cavitation occurrence or in increase of themagnitude of the already present cavitation [18]. Bregliozzi, et al. [19], assessed steels which showed that the grain size of the steels has an important effect on the nature of erosion produced on the surface of the samples. The resistance to cavitation erosion increases continuously with decreasing grain size. These experiments showed that cavitation erosion resistance of the steel increases if there is an increase in the mechanical properties. They used water with different pH values in the experiments and observed that the erosion rate changes by varying pH value. Decreasing pH values caused an increase in cavitation damage [19]. Jazi et al. [22] considered the influence of different flow rates on cavitation. They showed that more bubbles collapse in higher flow rates, also they mentioned that cavitation bubbles occurring in higher flow rates have higher energy; hence more erosion is expected. Auret et al. [15] which used water in their experiments about cavitation showed that the erosion rate increased as a function of water temperature and it reaches a maximum amount at approximately 65ºC (for copper and aluminum). Kwok et al. [16] found this temperature about 50ºC for stainless steel. They used water in experiment to predict the erosion rate of stainless steel caused by cavitation. Erosion rate functionally increased as temperature increased from 10 to 50ºC. Yoshiro Iwai et al. [17] concluded that different surface tension of water can affect the erosion. They adjusted the value of surface tension by adding photographic wetting agent, ranging from 0.0025 to 3.0%. They saw that the erosion rate decreases gradually with addition of wetting agent. Also they observed that the size and the number of large bubble clusters reduced due to the reduction of surface tension, which is the reason why the erosive power decreases with the reduction of surface tension. Vapor pressure can affect erosion rate in cavitation. It was reported that when vapor pressure increased, the number of bubbles increases, and therefore increases the erosion rate. It can also be said that the temperature dependence of the erosion rate is due to the increase of the relative vapor pressure [20]. Takashi Naoe et al. [21] worked on the influence of tensile stress on cavitation erosion. They say that in the steady state, it is clearly recognized that the mean depth of erosion as calculated by weight loss was increased by the imposed tensile stress. The tensile stress enhances crack propagation and accelerates erosion. The amplitude of imposed tensile stress is in accordance with the range of elastic deformation. The gas (air) content in liquid also can influence on cavitation. Altering the gas content in liquid, different values of cavitation can be achieved. We can see that cavitation grows when the gas content in the liquid is increased; hence cavitation erosion can be controlled by controlling the air content in liquid [18].

C. Cavitation Machining

Machining, with taking advantages of cavitation process is presented as an innovative method of machining in micro-nano scales. By employing a proper ratio of abrasive particles in the conveyor liquid in this method, the possibility to raise cavitation erosion rate is achieved. Thus this method can be employed in molecular and atomic scale machining. If a bubble created by the cavitation is taken as asphere, the abrasive particles of the liquid are scattered upon the sphere’s surface. Explosion of the bubbles causes the abrasive particles to thresh to the work piece surface and, consequently, creates molecular (or atomic) chip removal from the part. For a maximum output in machining two set of parameters must be considered and controlled. First set is the ones regarding the abrasive particles. Material removal rate can be controlled with a careful selection of these parameters. The other set is those related to cavitation. These parameters must be selected carefully in order to achieve maximum cavitation and consequently maximum erosion in procedure.

III. PARAMETERS ASSOCIATED WITH ABRASIVE PARTICLES

These parameters include the particle’s size, material, shape and the portion of abrasive particles in the conveyor liquid. In similar processes, aluminum oxide, boron carbide, and Silicon Carbide are utilized because of their hard substance. They can also be used in this process because the mechanism is the same. In case of shape, they must be sharp, but not spheroid, to simplify the chip removal.

IV. PARAMETERS RELATED WITH CAVITATION MACHINING

A. Cavitation Number

Reduction of this number increases the erosion. Thus, this number must be keep low as possible. This number is can be controlled by means of upstream and downstream pressure around the orifice.

B. Density of Energy Flux

Thisparameter can be determined from Equation (1). The higher the energy, the more the erosion. The minimum amount of J to create cavitation is 10 W/m^2. The amount of parameters in equation (1) must be carefully selected so that J reaches the maximum.

C. Flow Rate and Grain Size

Increment in flow rate can increase cavitation and energy of bubbles which increase erosion. In the case of steel, the grain size affectscavitation erosion, so that a better machining is achieved with big size grains. So if the grain size is bigger, faster machining is ensued.

D. Gas Content

With expansion of air in the conveyor liquid, increases cavitation for a higher rate of chip removal a certain portion of air must be mixed with the conveyor liquid and then the mixture must be entered to the system.

E. Value of pH When Using Water As The Liquid

The more acidic water ($pH<7$) the more cavitation erosion, so an aqua with a certain portion of acid can increase pace of erosion.

F. Temperature of Liquid

Increase of temperature to a certainrate, can increase in cavitation. Hence, governing the temperature can control over cavitation.

G. Surface Tension

The power of erosion decreases inaccordance with surface tension. Therefore, the setting must be helping to increase the surface tension.

H. Vapor Pressure and Tensile Stress

The impure particles in the liquid decrease the vapor pressure. For example, a little salt dissolved in water can decrease vapor pressure. So the liquid should be pure.Applying tensile stress round the elasticdeformation results in more erosion rate. More material removal rate is a result of applying tensile stress to machining part.

The above 8 parameters are the most effective ones in cavitation. Machining speed can be manipulated with effectual control of these factors.

Cavitation machining (CM) is controlled by two factors:

1) Hydrodynamic Cavitation Machining (HCM).
2) Ultrasonic Cavitation Machining (UCM).

V. ULTRASONIC CAVITATION MACHINING (UCM)

The USM machine, this method can be utilized as in **Fig. 1.**

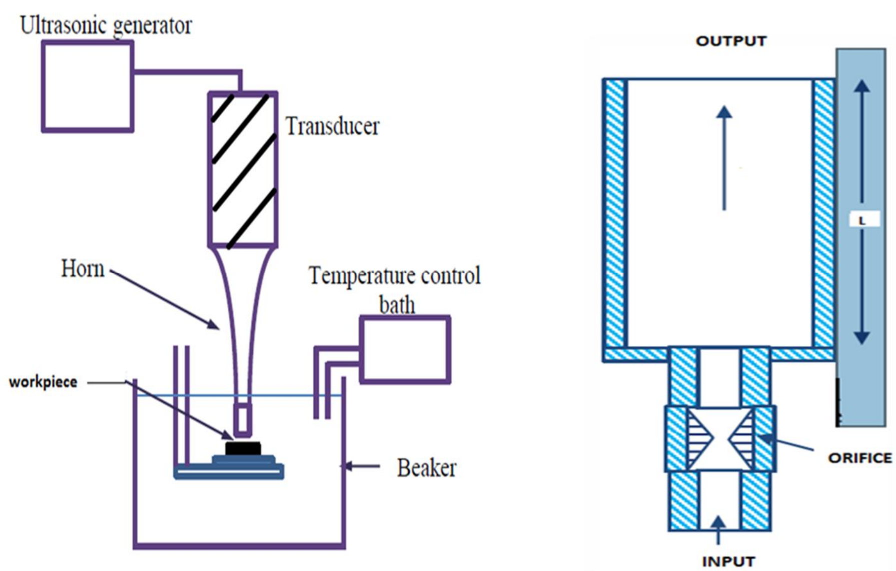

Figure. 1. The Ultrasonic Cavitation Machine

In this method, horn vibration causes local pressure decreases and creates cavitation bubbles amongst tool and the work piece. Along with the mentioned parameters, amplitude and frequency of vibrations also contribute to process control. Also the distance between the tool and the work piece must be several times the size of the abrasive particles. In this method, machining of each part is possible in a single time and the shape of machined part follows the tool's shape. This method can be employed to finish the initials surface with the holes and for the precise parts.

VI. HYDRODYNAMIC CAVITATION MACHINING (HCM)

This method can be utilized as shown in **Fig. 2**. This process needs a hydraulic system to mix the liquid and abrasive particles together with proper proportion, and drives them to the orifice and to work piece container with a certain pressure. The decrease in pressure of the work piece container results in creating cavitation bubbles. Traveling toward the boarders, the bubbles hit the work piece surface with the abrasive particles and remove the chip.

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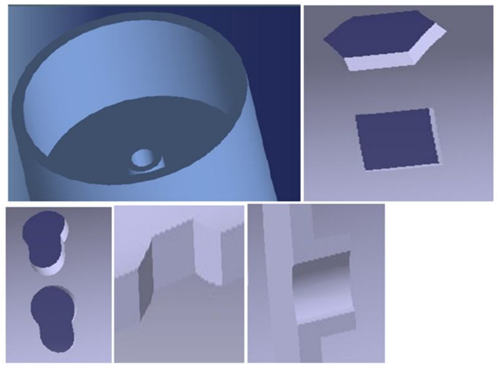

Figure. 2. Products can be produced by Hydrodynamic Cavitation Machining (HCM).

Also the conveyor liquid flows in work piece container and drags the abrasive particles on the work piece surface; hence, molecular (or atomic) chip removal is expected. As obvious in the **Fig. 2**, machining several parts, concurrently, with different shapes is possible in this method. Plastic washers can be used in order to maintain the work piece in the holes and caulking them.Chip removal rate can be controlled, in both methods, by means of time control so that chip removal of the parts can be managed.

VII. CONCLUSION AND FUTURE SCOPE

This paper presents andintroduces a new method of Non-conventional machining (NCM) by using the cavitation processand using **Cavitation**. UCM and HCM methods were also introduced and explained. Moreover, the operative parameters which are used in the process were analyzed. These parameters involve: density of energy flux, cavitation number, grain size, pH amount, flow rate, liquid temperature, surface tension, vapor pressure, tensile stress, and gas content. Machining pace and chip removal rate can be controlled by means of effectual observation of these factors. This method is a functional way for machining important parts with high accuracy and precision. Thus we can conclude that by employing NCM by Cavitation we have following advantages:

Benefits/Advantages implementation of Cavitation Machining (CM):

Great accuracy is possible

A. Concurrent machining is possible.
B. Absence of residual thermal stress.
C. There are no limitations of conductivity of materials, which might matter in other methods.
D. Overview of process especially the HCM process.

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