ABOUT some possibilities of influencing the energetic relief of metals, in order to favoring micro-joining processes

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ABSTRACT

The energetic relief depends on the nature of the considered element which has its own internal energy, cohesion, structure and other characteristic parameters.

Former experiences has shown that we could appreciate how and when a metal part was cut, with the aid of an electron counter system – in a determined period of time.

To join or aggregate metal parts – or particles like powder – we must reduce or eliminate the influence and effect of the energetic relief between the considered parts or particles. Different types of fields or energy may be applied in order to do that.

Authors experienced some kind of energies and studied the resulting plasma with the magnetohydrodynamic theory. They found that the variation of plasma density and the intensity of the magnetic field appears in a time interval which is under – or comparable – with the wavelength at this was the start point to develope further research. The experiences were made with the aid of an original device. Of course, after measuring and studying the main obtained data, authors have designed installation and devices, for industrial use.

One of the – economical – conclusion, was that is possible to influence the energetic relief in order to diminish costs of all type of aggregation processes, like sintering, welding a.s.o. In the same time, the processing time, may be reduced.

Keywords: Potential barrier, energetic relief, laser plasma, concentrated energy source.

1. INTRODUCTION

When we have to bore or to cut a piece of steel by means of laser beam, we may observe some important parameters like: metal machining rate, precision, roughness, the heat affected zone a.s.o.

During machining, some factors are disturbing the process, reducing the efficiency and in the same time, influencing the above mentioned parameters.

The main disturbing factors are the laser plasma produced by the melted material and the potential barrier which is a fonction of the nature of the machined material.
Authors studied some possibilities of reduce the negative influence of the potential barrier and laser plasma, on the machining parameters.
Potential barrier is an energetic relief and laser plasma as an effect, is the same. Some other energies or fields, directed against the machining zone, could interact positively and in this way to diminish their worst effects.

2. GENERAL CONSIDERATIONS

To study the laser plasma behavior, authors have used some elements of the magnetohydrodynamic theory, applied to plasma physics with an extension to laser plasma.

During machining, plasma appears in the space where the metal is melted, evaporated and finally eliminated. Plasma has a finite conductivity and the total flux thru a plasma layer is influenced by the existence of some phenomena which spread the plasma.

For homogeneous media, we could write:

\[ \frac{\partial B}{\partial t} = \text{rot} \{ u \cdot B \} - v_m \text{rot} \text{rot} B \]  

(1)

Where \( v_m = \frac{\varepsilon^2}{4 \mathcal{E} \sigma} \)

If the dimension of spacial elements is \( L \) and the characteristic speed is \( V \), we have:

\[ R_\sigma = \frac{v_L}{v_m} \]  

(2)

\( v_m \) has analogous dimensions with the coefficient of cinematic viscosity \( \nu = \frac{\mu}{\rho} \) and \( R_\sigma \) is analogous with Reynolds number from hydrodynamics, so we have a magnetic Reynolds number. When \( R_\sigma \gg 1 \), the term \( \frac{v_L}{v_m} \) from (2) could be neglect and the magnetic field in the considered plasma is stationary. To study the effect, when \( R_\sigma \ll 1 \), \( \text{div} \ B = 0 \) and

\[ \text{rot} \text{rot} a = \text{grad} \text{div} a - \Delta a \]  

(3)

We have:

\[ \frac{\partial B}{\partial t} = v_m \Delta B \]  

(4)

Such relations explain the diffusion phenomena due to the contraction gradient and the thermal conductibility phenomenon due to the temperature gradient. The equation (4) describes the diffusion of magnetic field into the plasma. If the magnetic field of the plasma is unhomogeneous the characteristic time for such unhomogeneity is:

\[ t_0 = \frac{t^2}{v_m} \]  

(5)

The period \( t_0 \) is a fonction of plasma electrical conductivity. The higher the conductivity, the slower the diffusion. When the diffusion of the magnetic field is increased, the total energy of the magnetic field is lower. When the nonhomogeneous formation is very low, in a period given by (5) the magnetic field into the plasma is amortized. The period \( t_0 \) is characteristic for the diffusion process and also for the amortization. For the speed of magnetic field diffusion, from the equations presented already, we can write:

\[ u \approx \frac{d}{t} \approx \frac{v_m}{d} \]  

(6)
where \( d \) is the depth of the magnetic field penetration into the plasma, in a time \( t \) which could be written as in the equation (4). The equation (6) gives us also the relative speed of the force lines to plasma.

If the magnetic field is variable with \( \nu = 1/t \), from (4) we may determine the thickness of the skin layer in which could penetrate the magnetic field into the plasma.

\[
\delta = \sqrt{\frac{m}{\nu}}
\]  
(7)

An electric current, may be produced also by an temperature gradient, not only by electromagnetic phenomena. Writing a Maxwell equation like

\[
\text{rot} \ B' = \frac{4\pi}{c} j'
\]  
(8)

such a current produces a supplementary magnetic field which adds to the magnetic field already existing to the plasma. For the total current, we could write:

\[
j = \partial E + j'
\]  
(9)

and using the equation:

\[
\text{rot} E = -\frac{1}{c} \frac{\partial B}{\partial t}
\]  
(10)

we have:

\[
\frac{\partial B}{\partial t} = -\text{rot}(\vec{v}_m \text{rot}B) + \frac{4\pi}{c} \text{rot}(\vec{v}_m j')
\]  
(11)

### 3. USING ULTRASOUND TO DIMINISH THE EFFECTS OF ENERGETIC RELIEF

There are electrical-mechanical-acoustic devices which could concentrate the ultrasonic oscillations in a technologic medium. Such devices are adapted to each particular situation, that means the dimension and shape of each target. They could transport and transmit the acoustic radiation at the point – for instance – where take place the impact of the laser beam, with the target. An „acoustic radiator” has characteristics as: the frequency, the directivity and the efficiency of the radiation. The terminal part of the radiator, is adapted to the scope. We could consider for example a pulsatory sphere, which pulses and radiate an uniform field of spherical waves.

For the superficial speed \( v_s \) we could write:

\[
v_s = v_0 \exp(j\omega t)
\]  
(12)

where \( v_0 \) is the amplitude of the superficial speed. For the acoustic pressure at a point which is at the distance \( r \) from the centrum of the sphere, we have:

\[
p = j p_0 \omega \frac{a^2 v_0}{r(l + ka^2)} (l - jka) \exp\{j[\omega t - k(r - a)]\}
\]  
(13)

where:

- \( p_0 \) is the medium density,
- \( ka = 2\pi a/\lambda \) represents the ratio between the source dimensions and the wave length of the emitted sound.
If we consider $Q$ the source hardness – the product between the surface and the speed $Q = sv_0$, for the acoustic pressure $p$, and $Q = 4\pi a^2v_0$ we could write:

$$p = j\omega \frac{p_0}{4\pi r(1+k^2a^2)}(1 - jka)Q \exp[j(ot - k(r - a))]$$  \hspace{1cm} (14)

If the wave length of the emitted sound is smaller than the diameter of the pulsed sphere ($ka > 1$) we have:

$$p \cong \frac{p_0c}{4\pi ra}Q \exp[j(ot - k(r))]$$ \hspace{1cm} (15)

this shows that the acoustic pressure depends of the source dimensions.

For the intensity of the acoustic waves, $I$, we have:

$$I = \frac{p_{\text{max}}^2}{2p_0c} = \frac{p_0c k^2Q^2}{32\pi^2r^2(1+k^2a^2)}$$ \hspace{1cm} (16)

The total acoustic power is

$$P_t = I S = \frac{p_0c k^2}{8\pi} \frac{Q^2}{1+k^2a} = 2\pi p_0c a^2v_0^2 \frac{k^2a^2}{1+k^2a^2}$$ \hspace{1cm} (17)

For low frequencies ($ka < 1$) the acoustic power $P_l$ is:

$$P_l \cong \frac{2\pi p_0c a^2v_0^2}{c}$$ \hspace{1cm} (18)

and for high frequencies, $P_j$ comes:

$$P_j = 2\pi p_0 c^2 a^2 v_0^2$$ \hspace{1cm} (19)

Another characteristic is the radiation impedance $Z_r$, defined as a ratio between the radiator force and particle moving speed $v_r$:

$$Z_r = \frac{F_r}{v_r} = \frac{P S}{v_r}$$ \hspace{1cm} (20)

For a pulsatory sphere, $Z_r$ becomes

$$Z_r = 4\pi a^2 p_0 c \left[ \frac{k^2a^2}{1+k^2a^2} + j \frac{ka}{1+k^2a^2} \right]$$ \hspace{1cm} (21)

The real part of $Z_r$ – the radiation impedance is:

$$R_R = 4\pi a^2 p_0 c \left[ \frac{k^2a^2}{1+k^2a^2} \right]$$ \hspace{1cm} (22)

and $X_R$ is:

$$X_R = 4\pi a^2 p_0 c \frac{ka}{1+k^2a^2}$$ \hspace{1cm} (23)

for low frequencies:

$$R_{R,l} = 4\pi a^2 p_0 c (k^2a^2)$$ \hspace{1cm} (24)

$$X_{R,l} = 4\pi a^2 p_0 c (ka)$$ \hspace{1cm} (25)

and for high frequencies, ($ka > 1$)
\[ R_{RL} = 4\pi a^2 p_0 c \quad \text{and} \quad X_R = \frac{4\pi a^2 p_0 c}{ka} \] (26)

The conclusion is, that for low frequencies the pulsatory sphere works better than in high frequencies. If we consider a pulsatory cylinder, with an a radius, smaller as the ultrasound wave length, is a variable in time:

\[ v = v_0 \exp(-j\omega t) \] (27)

The speed of the \( v_r \) particle is determined by:

\[ v_r = \frac{1}{j\omega p_0} \frac{\partial p}{\partial r} \] (28)

in which \( p \) is the acoustic pressure in an point at the distance \( r \), perpendicular on the cylinder axis:

\[ p = A \left[ J_0(k_1 r) + jN_0(k_1)\right] \exp(-j\omega t) \] (29)

where: \( A \) is the complex amplitude and \( J_0 \), \( N_0 \) are Bessel functions.

For \( r \to 0 \), \( p \to \infty \approx j \ln \left( \frac{2A}{\pi} \right) \exp(-j\omega t) \) (30)

For \( r = a \) the radial speed for a particle is:

\[ v_r = \frac{2A}{\pi p_{0}\omega a} - \exp(-j\omega t) \] (31)

A cylindric wave \( A \), has the amplitude:

\[ A = \frac{\pi p_{0}\omega a}{2} v_0 \] (32)

when \( r > a \) the acoustic pressure

\[ p_{r\to\infty} \approx A \frac{2}{\pi kr} \exp\left[ -j \left( \omega t - k r - \frac{\pi}{4} \right) \right] \] (33)

For the acoustic pressure, we have:

\[ p = p_0 a v_0 \sqrt{\frac{\pi \omega}{2r}} \exp\left[ -j \left( \omega t - k r - \frac{\pi}{4} \right) \right] \] (34)

for the acoustic intensity we have:

\[ I = \frac{p_{\max}^2}{2p_0} = \frac{\pi p_0 c k a^2 v_0^2}{4r} \] (35)

and for the acoustic power:

\[ P = \frac{\pi^2}{2} p_0 c k a^2 v_0^2 \] (36)

For a pulsed cylinder the acoustic intensity decreases to the source axys, while at the pulsed sphere the acoustic intensity decreases with the distance square.

If we take the case of a vibratory piston, we consider a disk with a radius \( a \) in Oyz plane, the axys Ox, perpendicular on the disc center.

If we consider a point \( M \) in the space in which the piston radiates, an element from the piston surface could be defined by polar coordinates \( \sigma \) and \( \varphi \)
So: \( v = v_0 \exp(-j\omega t) \)  

The acoustic pressure in the point M is:

\[
p = j \frac{p_0 c k a^2}{2 r} - v_0 \exp[j(\omega t - kr)] \left( \frac{2f_1(ka \sin \theta)}{ka \sin \theta} \right)
\]

(38)

The acoustic intensity in the point M is:

\[
I = \frac{p_0 c k^2 a^4 p_0^2}{8r^2} \left( \frac{2f_1(ka \sin \theta)}{ka \sin \theta} \right)^2
\]

(39)

The acoustic pressure and acoustic intensity a variables of point position with the piston. So, the piston has also the role of directivate.

Because of the acoustic intensity is maximum on the axys,

\[
I_0 = \frac{p_0 c k^2 a^4 p_0^2}{8r^2}
\]

(40)

and for the directivity function \( \Phi(\theta) \),

\[
\Phi(\theta) = \frac{2f_1(ka \sin \theta)}{ka \sin \theta}
\]

(41)

The points in which the acoustic intensity is minimum, are:

\[ ka \sin \theta = 3,83; 7,02; 10,15 \]

(42)

This is a sphere with the radius \( r \), and the polar angle \( \theta \), according to figure 1:

\[ ka \sin \theta_i = 3,83 ; \theta_i = \arcsin \left( \frac{0,61}{a} \right) \]

(43)
4. CONCLUSIONS

Theoretical and applied study, authors have done, are showing that it is possible to influence an energetic relief – the Potential Barrier – situated on the surface on a metallic target, with a concentrated energy source, that could be: magnetic field, ultrasound, microwave and also other sources.

For each situation: type of process, nature of target material, dimensions a.s.o., we may adapt the reciprocal position and working parameters.

Anyway, the costs are very low, but the advantages concerning the diminution of H.A.Z., the precision, the roughness, the metal removal rate, could be of high interest.

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