A COUSTIC EMISSION AT CHANGE OF MECHANICALLY DESTRUCTION COMPOSITE MATERIAL PROPERTIES

Prof., DSc Filonenko S.F.
National Aviation University – Kyiv, Ukraine, filso101@gmail.com
Prof., Ph.D. Eremenko V.S.
National Aviation University – Kyiv, Ukraine, nau_307@ukr.net

Abstract: The regularity of acoustic radiation energy change in time at change of machining composite material properties for a case of prevailing mechanical destruction its surface layer are obtained. It is shown, that the change of machining composite material properties does not influence nature of acoustic radiation. Is determined, that the ascending of parameter, that describing of composite material property, results in decreasing of acoustic emission signal energy. It is shown, that the dispersion of acoustic emission average level energy has the greatest dip.

KEYWORDS: ACOUSTIC EMISSION, COMPOSITE MATERIAL, RESULTANT SIGNAL, DESTRUCTION, ENERGY, MACHINING, CONTROL.

1. Introduction

The control and monitoring of composite materials (CM) machining are directed on assurance produced items quality. For solving of these problems the broad complex researches of CM machining technological processes with usage of different methods is carried out. One of researches methods is the acoustic emission (AE) method.

AE method is applied to research such processes as turning, drilling, milling, grinding of CM. The considerable registered information volumes and high sensitivity of AE method to the CM destruction processes at different levels complicate interpretation of AE signals parameters. The problem is aggravated also that on AE influences many factors. Such factors are the CM machining parameters, CM treated physical-mechanical characteristics, and also wearing of the treating tool.

The resultant acoustic radiation registered at materials machining, switching and CM, is reshaped at existence of different sources. These sources are connected with deformation and destruction processes of the materials. The suspected sources of acoustic radiation are reviewed in articles [1 - 3]. Such sources are considered: plastic deformation in the work piece; plastic deformation in the chip; destruction the work piece; friction contact between surface of work piece and treating tool; friction contact between chip and treating tool; chip and tool impact; chip breakage; tool fracture; phase transformations in work piece and other. However in experimental researches at machining materials esteem two types of AE registered signals: continuous signals; burst signals or transient signals. Continuous signals are associated with work piece surface layer deformation and destruction and shearing in the primary zone and wear on the tool face and flank, while burst or transient signals result from destruction (damage) of a cutting tool [4 - 8].

At research of CM machining processes is carried out the analysis of influencing different factors on acoustic radiation. Such factors are the parameters of machining technological processes - cutting speed, feed rate and cutting depth. However the results of researches have not allowed receiving extending legimiticities AE parameters change at change of technological factors values. Obtained regularity has composite and discordant nature of change. In article [9] is determined, that change of machining speed, feed rate and cutting depth results in minor increase of AE registered signal root mean square (RMS) amplitudes value and its power. Thus the obtained relations have not steady nature of change. Ascending of machining speed, as shown in article [10], results to not a scaling up mean and RMS of AE signal amplitude and amplitude average value standard deviations.

At the same time, at ascending the feed rate and cutting depths relations of AE amplitude parameters change have composite and not stable nature of change. The increase of AE signals amplitude (average value) at ascending of machining speed and cutting depth is showed in article [11]. Thus is established, that obtained regularity have practically linear nature of change. However on large cutting depth the obtained relations are not stable. Is watched the dip of AE signal amplitude. In article [12] is showed, that the ascending of machining speed results to decreasing of AE amplitude average value. Increasing the feed rate and the cutting depths have inverse influencing on AE, i.e. result in increase of AE registered signals amplitude average value. At the same, in [13] is marked, that ascending of all machining technological parameters (processing speed, feed rate and cutting depth) results in increase of AE signals RMS amplitude.

The simulation influencing of machining technological parameters on AE amplitude characteristics for mechanical model CM destruction surface layer is reviewed in articles [14, 15]. At simulation of AE resultant signals was considered, that at CM machining descends sequentially destruction the given size of surface layer elementary area. Destruction of each CM elementary area descends at the prevailing mechanical destruction mechanism and is accompanied by formation of AE single pulse signal.

The sequentially area destruction results in sequence appearance of AE pulse signals and the resultant AE signal presented in the next form

\[ U_p(t) = \sum_{j} U_j(t - t_j), \]

where \( t_j = j \Delta t_j \pm \delta \) - time moments of AE pulse signals \( U_j \) appear at the sequentially prevailing mechanical destruction of CM certain j-numbered areas; \( \Delta t_j \) - time interval between the beginning of the next AE impulse signal generation in regard to the previous one; \( j=0, \ldots, n; \delta \) - random component in time moment of appearance every next AE impulse signal, which conditioned by possible deviation of technological processes parameters.

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Statistical processing the simulation results, agrees (1), has shown, that ascending of CM machining speed result to scaling up of AE signal amplitude average level and its standard deviation [14]. However the dispersion of amplitude average level is augmented not by linear mode (is well described by exponential function). Similar influencing on AE has CM cutting depth. In article [15] is showed, that ascending of CM machining cutting depth result to scaling up of AE signal amplitude average level, its standard deviation. Dispersion of AE amplitude average level is augmented under the power law.

One of parameters that influential on AE at CM machining is its physical-mechanical characteristics. Research of their influencing on acoustic radiation energy parameters at prevailing mechanical destruction CM surface layer are introduced relevant for mining methods of verification and monitoring produced items quality.

The purpose of the article is definition of influencing CM treated properties at prevailing mechanical destruction surface layer on acoustic radiation energy.

2. Research tasks

For purpose achievement the following research problems were determined: to conduct simulation of acoustic radiation energy for a case of prevailing mechanical destruction surface layer at change of CM treated properties; to execute statistical data processing with definition of AE signals energy parameters values for adopted simulation conditions; to conduct the analysis influencing of CM treated properties on AE signals energy parameters change.

3. Solution of put problems

3.1. Simulation conditions.

Conditions of acoustic radiation formation at CM treated properties change we shall accept the same, as well as in articles [14, 15]. At constant parameters of machining work piece sequentially destruction CM elementary area in time is accompanied by sequentially AE signals pulse formation. Destruction of each elementary area descends at the prevailing mechanical destruction mechanism. Under such condition AE resultant signal energy is described by the following expressions

$$E_p (t) = \sum U_{jM}^2 (t - t_j),$$

where $t_j = jM j \pm \delta M$ – time moments of AE pulse signals $U_{jM}$ appear at the sequentially prevailing mechanical destruction of CM certain j-numbered areas; $\Delta t_j$ - time interval between the beginning of the next AE impulse signal generation in regard to the previous one; $j=0, ..., n$; $\delta M$ - random component in time moment of appearance every next AE pulse signal.

The random component in time $\delta M$ can be conditioned by instability of CM treated properties dispersion, instability of specimen rotation speed, instability of feed rate, instability of CM distraction area sizes or other factors. Such instability will influence on CM surface layer area destruction processes duration and duration of AE signals reshaped pulse.

At prevailing CM surface layer mechanical destruction the AE signal pulse amplitude $U_{jM}$ in time, agrees [14], is described by the following expressions

$$U_{j} (t) = u_{0} \tau^{\alpha \tau} e^{-\frac{t_0}{\tau}} (e^{r \alpha t} - 1),$$

where $u_0$ - maximum possible elastic displacement, which spread in the material during instant destruction of the given CM area; $\alpha$ - load speed; $u_0$, $\tau$ - constants, which are determined by CM physical and mechanical characteristics.

Expression (3) includes parameters $u_0$ and $\tau$, which are characterizing, accordingly, CM physical-mechanical properties and properties dispersion. At simulation we shall esteem change of parameter $u_0$.

3.2. Simulation results.

Simulation of acoustic radiation energy we shall conduct in relative units under following conditions. Parameters which are included in expressions (2) and (3) we shall put to non-dimensional values. Energy and time will be submitted in normalized units. Values of parameters $u_0$ and $\tau$ in expression (3) will be taken equal: $\tilde{a} = 20; \tilde{r} = 10000$. Initial value $\Delta t_j = 0.000007$. The value of $\tilde{\delta M}$ is randomly changed in range from 0 up to $\tilde{\delta M} = 0.000082$. The value $u_0$ we shall change in range of sizes from $\tilde{u}_0 = 100000$ up to $\tilde{u}_0 = 500000$ with a step of increment 100000. Analysis of AE pulse signals, agrees (3), has shown, that to ascending $\tilde{u}_0$ there is decreasing of AE reshaped signals duration. Outgoing from this, for other values $\tilde{u}_0$ values $\Delta t_j$ and $\tilde{\delta M}$ we shall reduce proportionally to decreasing of AE pulse signals duration.

The simulation results in the form of acoustic radiation energy change in time in relative units for different values $\tilde{u}_0$ are shown in the fig.1. In the graphs fig.1 time is normalized on the time of CM surface layer development destruction process. During the
From the above results (table 1) we can see that an initial value \( \tilde{v}_0 \) the AE signal energy parameters in relative units are equal: AE signal energy average level - \( \bar{E} = 3.3498 \times 10^{-4} \); AE signal energy average level standard deviation - \( s_{E} = 2.8945 \times 10^{-4} \); AE signal energy average level dispersion - \( \sigma_{E} = 8.3781 \times 10^{-8} \). The increase of \( \tilde{v}_0 \) in 2 times (up to \( \tilde{v}_0 = 200000 \)) leads to decreasing of AE signal energy average level \( \bar{E} \), its standard deviation \( s_{E} \) and dispersion \( \sigma_{E} \), accordingly, in 1,5561 times, in 1,5814 times and in 2,5009 times. At the ascending \( \tilde{v}_0 \) in 3 times (up to value \( \tilde{v}_0 = 300000 \)) there is decreasing values of AE signal energy parameters \( \bar{E} \), \( s_{E} \) and \( \sigma_{E} \), accordingly, in 1,8728 times, in 1,9773 times and in 3,9096 times. The further ascending \( \tilde{v}_0 \) in 4 times (up to value \( \tilde{v}_0 = 400000 \)) leads to decreasing values of AE signal energy parameters \( \bar{E} \), \( s_{E} \) and \( \sigma_{E} \), accordingly, in 2,1582 times, in 2,3494 times and in 5,5197 times. At the ascending \( \tilde{v}_0 \) in 5 times (up to value \( \tilde{v}_0 = 500000 \)) there is a further decreasing of AE energy parameters \( \bar{E} \), \( s_{E} \) and \( \sigma_{E} \), accordingly, in 2,2928 times, in 2,6729 times and in 7,1447 times.

3.3. Regularity of acoustic radiation energy parameters change.

According to the data of tab. 1, in fig. 2 are added regularity of AE signal energy average level, its standard deviations and dispersions change depending on parameter \( \tilde{v}_0 \).

The obtained results (fig. 2) demonstrate that relations of AE signal energy average level change, its standard deviation and the dispersions with ascending of parameter \( \tilde{v}_0 \) have not linear nature of decreasing.

The approximating of the data has shown, that the relations of AE signal energy average level change, its standard deviation and dispersions (fig. 2) are well described by non linear functions of kind

\[
(4) \quad \tilde{Z} = \tilde{c} \tilde{v}_0^d, 
\]

where \( \tilde{Z} \) - AE signal energy average level or its standard deviation or its dispersions; \( c \) and \( d \) - coefficients of approximating expression.

The obtained results (fig. 2) demonstrate that relations of AE signal energy average level change, its standard deviation and the

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**Table 1. AE resultant signal energy parameters at ascending value of parameter \( \tilde{v}_0 \), which is characterizing CM physical- mechanical properties**

<table>
<thead>
<tr>
<th>( \tilde{v}_0 )</th>
<th>( \bar{E} )</th>
<th>( s_{E} )</th>
<th>( \frac{\sigma_{E}}{\bar{E}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>100000</td>
<td>3.3498 \times 10^{-4}</td>
<td>2.8945 \times 10^{-4}</td>
<td>8.3781 \times 10^{-8}</td>
</tr>
<tr>
<td>200000</td>
<td>2.1528 \times 10^{-4}</td>
<td>1.8303 \times 10^{-4}</td>
<td>3.3501 \times 10^{-8}</td>
</tr>
<tr>
<td>300000</td>
<td>1.7886 \times 10^{-4}</td>
<td>1.4639 \times 10^{-4}</td>
<td>2.1429 \times 10^{-8}</td>
</tr>
<tr>
<td>400000</td>
<td>1.5521 \times 10^{-4}</td>
<td>1.2320 \times 10^{-4}</td>
<td>1.5179 \times 10^{-8}</td>
</tr>
<tr>
<td>500000</td>
<td>1.4609 \times 10^{-4}</td>
<td>1.0829 \times 10^{-4}</td>
<td>1.1726 \times 10^{-8}</td>
</tr>
</tbody>
</table>

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dispersions with ascending of parameter $\tilde{c}_0$ have not linear nature of decreasing.

![Graphs of AE resultant signals energy average level $\tilde{E}$ (■), its standard deviation $s_\tilde{E}$ (●) and dispersion $s_\tilde{E}^2$ (▲)](image)

change depending on parameter $\tilde{c}_0$, which is characterizing CM physical-mechanical properties, for the prevailing mechanical destruction surface layer

The approximating of the data has shown, that the relations of AE signal energy average level change, its standard deviation and dispersions (fig. 2) are well described by non linear functions of kind

\[ \tilde{Z} = c\tilde{c}_0^d, \]

where $\tilde{Z}$ - AE signal energy average level or its standard deviation or its dispersion; $c$ and $d$ – coefficients of approximating expression.

The coefficients values $a$ and $b$ of approximating expression (4) make: for the AE signal energy average level - $c = 0.18035, d = 0.54741$; for the standard deviation of AE signal energy average level - $c = 0.35684, d = 0.61864$; for the dispersion of AE signal energy average level - $c = 0.16187, d = 1.25751$. Thus determination coefficients $R^2$ at the description of AE resultant signal energy average level, its standard deviations and dispersion, accordingly, make: $R^2 = 0.99038; R^2 = 0.99869; R^2 = 0.9991$. Selection criteria of approximating functions for the description of relations fig. 2 would be the minimum of residual dispersion.

For definition sensitivity of AE signals energy parameters to increasing of parameter $\tilde{c}_0$ we shall conduct data processing (tab. 1) with definition of percentage decreasing of AE signal energy parameters at increasing $\tilde{c}_0$, in relation to their initial values at $\tilde{c}_0 = 100000$.

The results of data processing are shown in fig. 3, where the following notations are adopted: $\Delta Z$ - percentage decreasing of AE resultant signal energy average level or its standard deviation or its dispersion; $\tilde{c}_0$ - parameter, which is characterizing CM physical-mechanical properties.

The results are shown that with increasing of parameter $\tilde{c}_0$ the percentage decreasing of AE signal energy average level dispersion advances a percentage decreasing of energy average level and its standard deviation (fig. 3). Truly, at increasing parameter $\tilde{c}_0$ in 3 times (with $\tilde{c}_0 = 100000$ up to $\tilde{c}_0 = 300000$) percentage decreasing of AE signals energy parameters (energy average level $\tilde{E}$, its standard deviation $s_\tilde{E}$ and dispersions $s_\tilde{E}^2$), accordingly, make: 46.61%, 49.43% and 74.42%. At increasing parameter $\tilde{c}_0$ in 5.0 times (up to value $\tilde{c}_0 = 500000$) percentage decreasing of AE signals energy parameters, accordingly, make: 56.39%, 62.59% n 86.00%.

![Graphs of the percentage decreasing AE resultant signals energy average level $\frac{\Delta E}{E}$ (■), its standard deviation $\frac{s_E}{E}$ (●) and dispersion $\frac{s_E^2}{E}$ (▲)](image)

The research results demonstrate, that at prevailing mechanical destruction CM surface layer the increasing of parameter $\tilde{c}_0$, which is characterizing CM physical-mechanical properties, should be accompanied by decreasing of acoustic radiation energy average level, its standard deviation and dispersion. Thus the decreasing of AE energy average level dispersion advances decreasing an energy average level and its standard deviation. In other words, the greatest reacting to change of CM properties is watched in dispersion of AE resultant signal energy average level.

4. Resume

The research of influencing of treated CM properties for a case of prevailing mechanical destruction its surface layer on acoustic radiation energy parameters is conducted. It is shown that change of treated CM properties does not result in acoustic radiation nature change. However is accompanied by decreasing of AE signals energy average level and value of its deviation. By the results of statistical data processing for given values of parameter, which is characterizing CM physical-mechanical properties, the
values of AE signals energy parameters are obtained - energy average level, its standard deviation and dispersion. The analysis influencing of treated CM properties on AE signals energy parameters change is conducted. It is shown, that ascending value of parameter, which is characterizing CM physical-mechanical properties, results in decreasing of all AE energy parameters. Is determined, that decreasing of AE signals energy average level dispersion advances decreasing energy average level and its standard deviation.

The results of conducted researches can be used at mining methods of CM machining technological processes verification, diagnostic and monitoring, directional on maintenance the control of work piece irregularity properties.

4. References


