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Application of acoustic emission method in punch press monitoring

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Acoustic Emission (AE) signals generated in different stages of punch process are analysed. The details of the instrumentation used are described. The experimental part describes: the influence of feedstock thickness and hardness to the intensity of the emitted signal, the changes of AE signal caused by simulated tool abrasive wear and the dependence between the number of razors in multi-element progressive punch on the emitted signal. The possibilities of AE monitoring of punching of thin plates are also discussed.

1. Introduction

The stress wave caused by the energy release in stressed solids is called the Acoustic Emission (AE) effect. AE sources are crack formations, generation or annihilation of dislocations and friction processes. The AE technique has been developed for monitoring the processes in various branches of industry. Application of acoustic emission in punch press monitoring is focused to avoid catastrophic failures of tools and machines and to reduce expensive machine maintenance cost by an early detection of any abnormal condition. The advantages of application of AE technique versus traditional method of strain gauge punching force monitoring appear more clear when thin plates are subject to press processing. In this case the weight difference between the workpiece and the feedstock is too big for the proper reproduction the effects appearing during the punching process. The application of AE measurements in punch press working was described in various papers. Among them [1] and [2] can be recommended as detailed research descriptions. AE monitoring of friction processes caused by deep drawing of sheet metal is discussed in [3]. Some information about the principles of AE technique applied to control friction processes can be found in [4].

Our aim in this paper is to point out the influence of feedstock sheet thickness and hardness on the intensity of the emitted AE signal. The other part of the investigation presents the changes of AE signal caused by simulated tool abrasive wear. This enables to detect the failure of the process. The next part of the presented paper describes the AE signals generated during the operation of the multi-element progressive punch.

2. Experiments made on one-shot punch

The investigation of punching process described below was performed using 5 ton capacity, pneumatic crank PMSC – 12 punch press. The steel rod of 20 mm in diameter and 100 mm long was attached to the press die-set at the position found experimentally. At the end of this rod the wideband 90-900 kHz AE transducer, manufactured by American Physical Acoustic Corporation, was fixed using metal bands and screw joints. The steel rod acted as a waveguide for the measured AE signal. Stress wave transmission of the waveguide was poor for the lower frequency band, generated by the press driving engine parts. Therefore, the rod has much better efficiency in transmission of the stress wave frequencies higher than 50 kHz and generated in workpiece-stock contact zone. The AE signal was processed in custom – made AE analyzer. The AE analyzer was capable to compute the root-mean-square (U RMS) of the registered electric signal what can be also described as deriving a square root of the AE signal energy. The U RMS parameter was calculated separately for the lower frequency band (50-100 kHz) and for the highest frequency band possible to receive (400-900 kHz). The AE analyser transmitted both values of the AE signal activity together with the current level of the force measured at the punch using the strain gauge method to the PC computer every 2 milliseconds via parallel port. The instrumentation described above enabled us to control the process with sufficient time resolution and to compare separately the intensity of the registered AE signal generated in low (U RMS L) and in high (U RMS H) frequency bands.

We have found that the registered AE signal generated during process of punching consists of three components: initial impact, shear fracture and the noise evoked by pulling the punch off the sheet. Two first components can often be recorded as one uninterrupted pulse train. The maximum of the AE intensity appears when plastic deformation zone reaches its greatest volume in the processed element. Under the conditions arranged in the

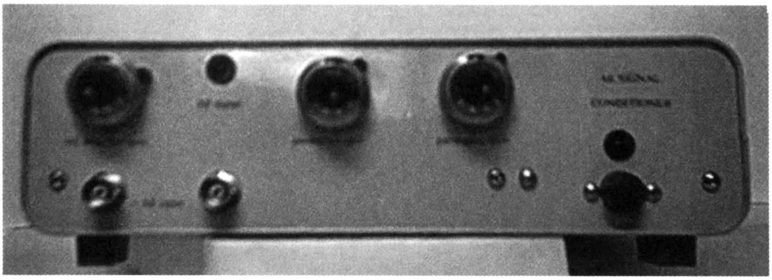

FIGURE 1. Industrial-type AE signal analyser used for monitoring the punching process. At the front side two BNC sockets to connect a differential wideband AE transducer are visible. An output signal – being an envelope of the amplified AE signal – is transmitted via a socket situated to the rear.

investigation described below the AE signal intensity registered during first two punch movement phases was similar to that registered by pulling-off the workpiece from the sheet. However the AE signal generated in high frequency band (U RMS H) during first two punch movement phases has higher intensity and shorter period than U RMS L, registered at the same time. This can be useful to recognize process phases by the means of AE signal monitoring. The following feedstock samples were used in the investigation: st 3 mild steel one and three millimetres thick, three millimetres thick stainless steel, 0.3 millimetres thick transformer (silico-manganese), and 0.3 millimetres thick stainless steel. After completing the introducing experiments the investigation included four samples of each stock type. The punch travel cycle lasted here 250 milliseconds. Later in this paper other examples of punching process will be discussed where the punch travel cycle was reduced to 40 milliseconds.

Experiments related to a process of punching of mild steel sheet are shown in Fig. 2.

The thick line denotes the punching force, both parameters measured in one punch travel cycle. We observe that the differences in the AE signal level measured in three separate cycles do not exceed 20 % of its current value. The first peak of AE signal intensity is delayed with respect to the punch force increase and is evoked by the plastic deformation processes. The second small burst of AE signal activity probably denotes the separation of the blank from the stock. The third peak of AE signal intensity is related to the noise evoked by pulling the punch off the sheet.

Figure 3 presents the comparison between U RMS L and U RMS H registered during punching processes of 3 mm thick mild steel sheet processing. Time dependence of punching force applied at the experiment is shown in up-

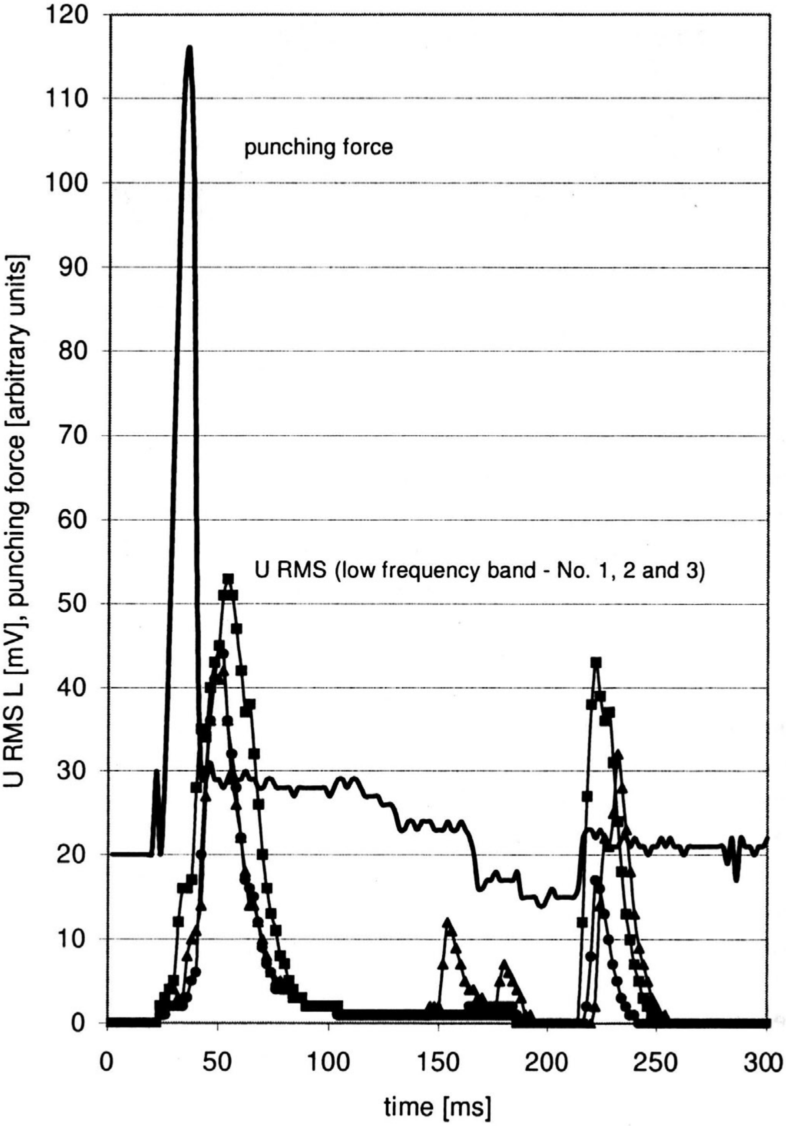

FIGURE 2. Punching of 1 mm thick mild steel sheet. Root-mean-square of AE signal in lower frequency band registered for three punching processes (marked as squares, circles and triangles) and punching force (thick line), both parameters measured in one punch travel cycle.

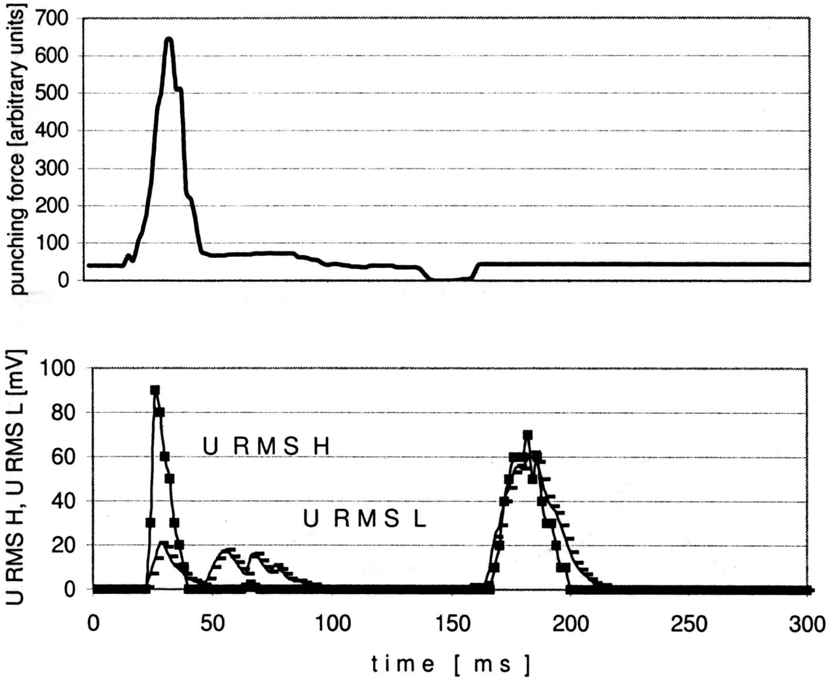

FIGURE 3. Punching of 3 mm thick mild steel sheet. U RMS H (squares) and U RMS L (horizontal dashes) and punching force (upper part of the Figure). High frequency activity of AE signal appears in early phase of stock plastic deformation.

per part of the Figure. High frequency activity of AE signal (the line marked with squares) appeared in early phase of punch intrusion into a sheet volume. During the phase of pulling the punch off the sheet the levels of U RMS L and U RMS H were nearly equal. Figure 4, registered during punching of 3 mm stainless steel processing, shows that both low and high frequency waveforms demonstrate longer duration as it was registered for mild steel. The noise generated by the intensive extrusion of the blank from the sheet is remarkable. The blank separation also produces an AE signal. High and low frequency activity of AE signal appears at the same time. We conclude that the material presenting longer plastic deformation behaviour generates stronger AE signal.

Figure 5 presents the comparison between U RMS L and U RMS H registered during punching processes of thin (0.3 mm) sheet plates. The intensity of registered acoustic emission signal was 20 dB – 10 times weaker than that registered in thick plates. To make the registration possible, an additional 20 dB increase of signal amplification was arranged. A punching force reg-

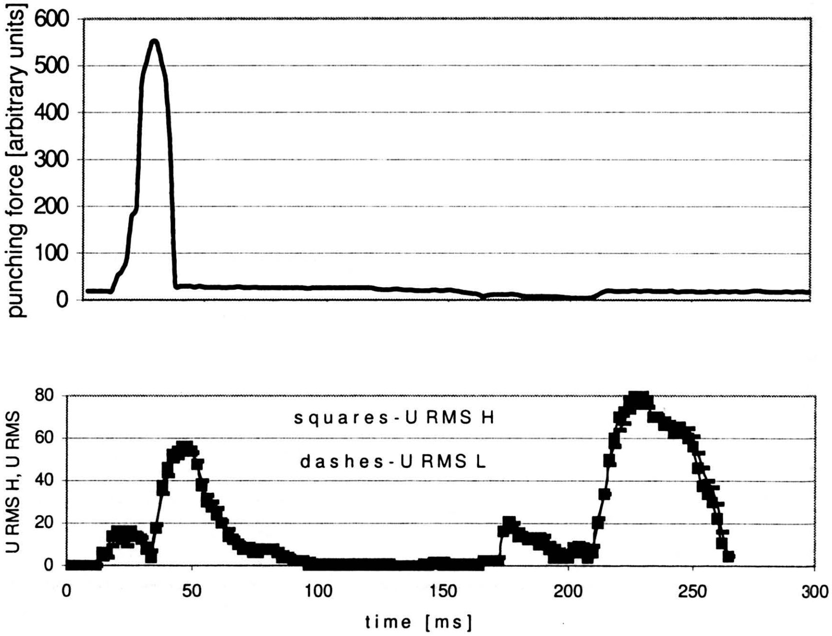

Figure 4. Punching of 3 mm thick stainless steel sheet. U RMS H (squares) and U RMS L (horizontal dashes) and punching force (upper part of the Figure). High and low frequency activity of AE signal appears in the same time in this process of increased plastic deformation.

istered by tensometric strain gauge was also ca. 10 times lower than in the previous cases. The resolution of the sensor used did not allow to measure the force evoked by pulling the punch off the plate, what appeared at about 160 ms delay after the intrusion phase. The positive peak at the right side of punching force plot denotes the stress wave generated at the crank movement break.

The central part of Fig. 5 shows AE waveform registered during punching the stainless steel plate. There is a significant signal burst during the plastic deformation phase. We note that AE signal generated in high frequency band increases and fades faster than low frequency component and therefore it can more precisely determine the process of punching. The small peak at about 80 ms delay is probably caused by shear fracture. The lower part of Fig. 5 shows AE waveform registered during punching the harder transformer steel plate. U RMS H burst amplitude is doubled if compared with the waveform registered in stainless steel. In this latter case there is no AE burst generated by shear fracture, but there are small peaks in the region when the punch is

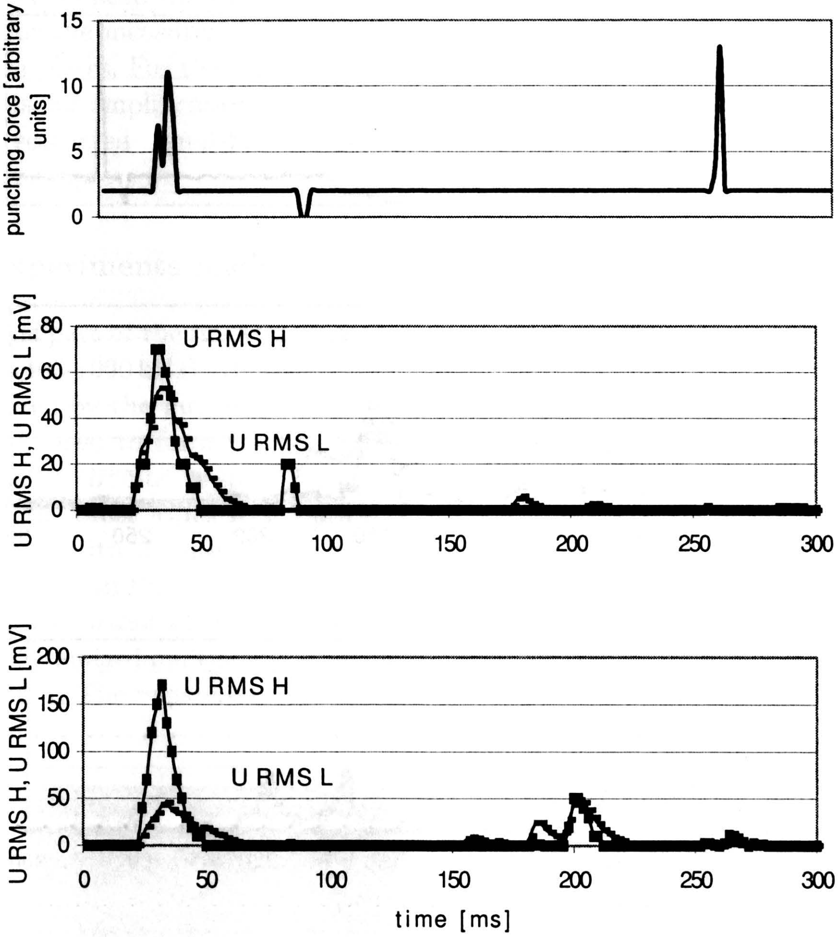

FIGURE 5. Comparison between URMS L and URMS H registered during punching processes of thin (0.3 mm) sheet plates of stainless steel (central part) and silico-manganese steel.

pulled off the plate. AE signal burst generated at plastic deformation phase seems to be 20% shorter than the burst registered in more ductile stainless steel case.

The next part of the investigation was aimed to register the AE activity at the abnormal press operating condition. The experiments were performed with 0.3 mm sheet stainless and transformer steel plates processed with the workpiece with dull-edged face. In this case the excessive plastic deformation process appeared prior to separation of the blank. A long 'fin' of metal at the edge of the blank was drawn out causing the additional friction component

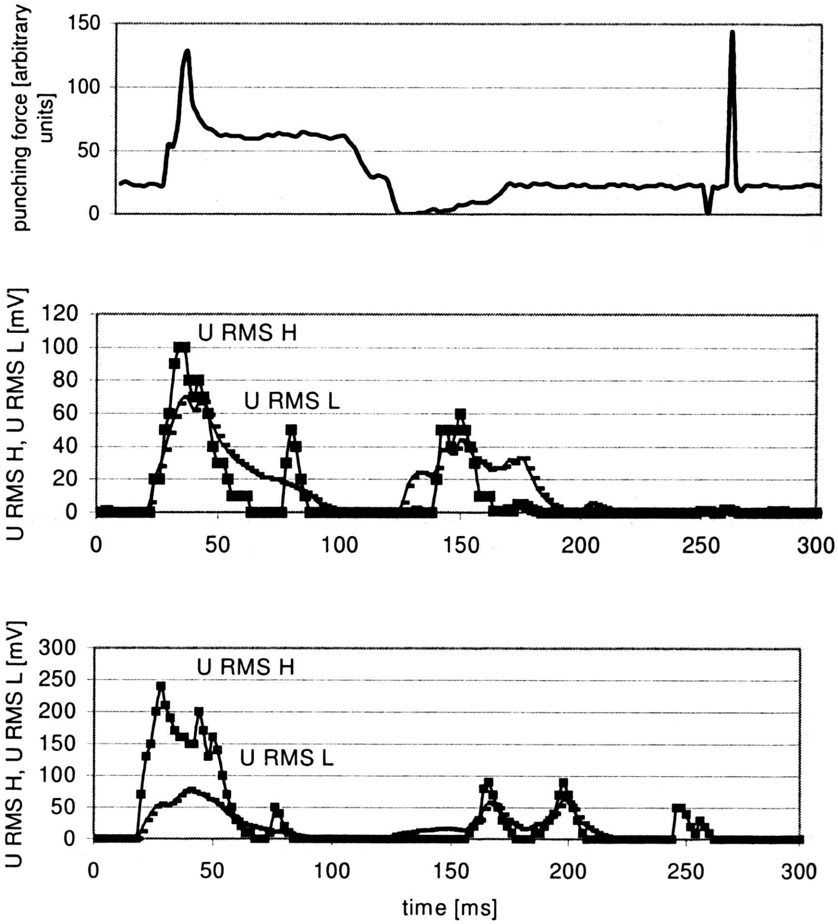

FIGURE 6. Punching performed on the material shown in Fig. 4, applying the workpiece with dull-edged face. Longer duration of the AE activity reflects the excessive plastic deformation process, prior to separation of the blank. Peak AE signal level, registered in transformer plate (lower section) is twice higher than that measured in stainless plate (central section of the Figure).

during punch extrusion. The processes described above are shown in Fig. 6. The ductility differences between two investigated steel compositions resulted in the depicted AE signal intensity. The peak AE signal level, registered in transformer plate and shown in lower section of Fig. 6, is twice higher than that measured in stainless plate (shown in the central section of the Figure).

Three ranges of specimen thickness were applied in the reported investigation, i.e. 3, 1 and 0.3 mm. The AE signal level decreases was observed together with a reduction of specimen thickness. Acoustic Analyser gain was modified to keep the proper recording conditions. 60 dB recording level was used for the measurements of 3 mm plates and 80 dB was adjusted for the 0.3 mm plates. For the majority of available AE recording systems the maximal useful amplification level equals 100 dB. Higher amplification requires more restricted signal filtering procedures to avoid the system instabilities and to suppress the background noise.

3. Experiments made on multi-shot progressive punch

This part of the investigation was performed in following way. The wideband (100-1000 kHz) AE sensor was placed directly on brass tape feedstock processed by the punch. The tape was 3/4 in. wide and 0.01 in. thick. This stock is used to form the contact frame for power transistors and specific integrated circuits. A special bracket holder was designed to fix the AE sensor to the brass tape. To suppress the background noise the AE signal was processed with the use of fourth-order 25 kHz high-pass filter. Further it was amplified with the ratio of 60 dB and finally its RMS value – converted with the time constant of 50 microsecond – was transmitted to one of two line inputs of standard multimedia sound analogue to digital converter of a personal computer. The registered signal was converted at the rate of 11025 Hz using

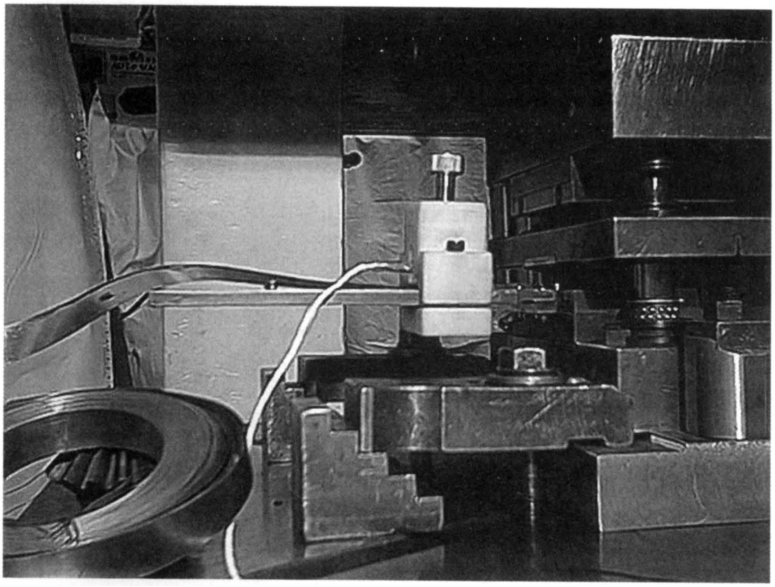

FIGURE 7. AE sensor placed in a holder directly on the feedstock tape at the left side of the multi-element progressive punch.

8-bit resolution. The signal to noise ratio of the converter was better than 60 dB. The AE waveform evoked by the punching process lasted ca. 40 ms and was followed by its echoes and signals generated by the press driving engine parts. Therefore the recognition procedure of the beginning of punching process was supported by the application of inductive positioning proximity sensor, placed near travelling workpiece. The triggering signal generated by proximity sensor was transmitted to the second line input of the sound card described above. Figure 7 presents AE sensor placed in a bracket holder directly on the feedstock tape at the left side of the multi-element progressive punch.

The workpiece of the punch included 6 smaller, conical razors and 6 greater, squared razors. The progress of the punching can be divided into 11 cycles shown in Fig. 9. The experimental work was focused on the assessment of changes in the AE signal intensity caused by modifications of punching conditions. Taking into account that there are several AE sources active during the described process and that their activity is evoked in time sequence, a proper AE descriptor should be chosen to describe the acoustic activity of the razors. We decided to analyse the totalised RMS level of a waveform, calculated according to the following formula:

$$U_t = \sum_{t_1}^{t_2} U_{RMS}(t_n), \tag{3.1}$$

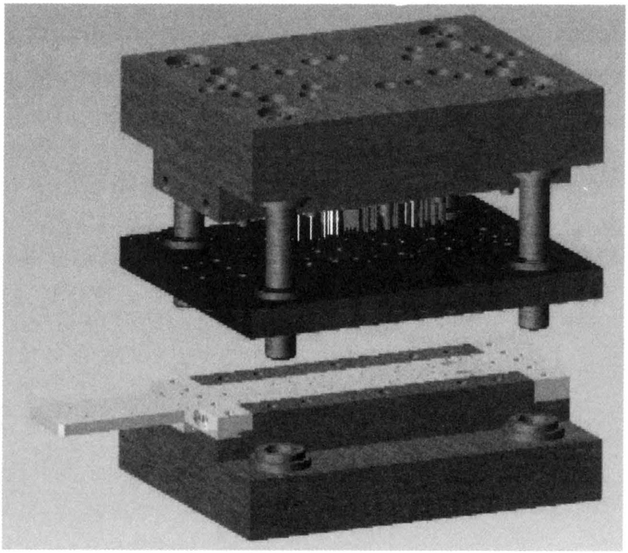

FIGURE 8. Schematic diagram of the multi-element progressive punch workpiece.

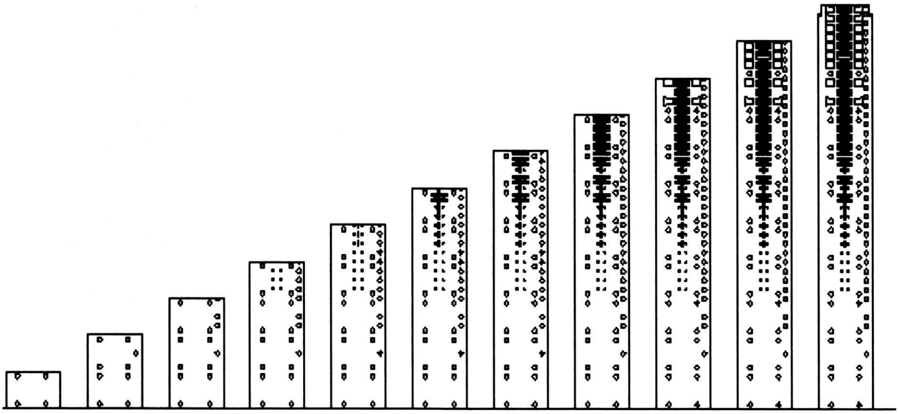

FIGURE 9. The progress of the punching, consisted of 11 cycles.

where $U_{RMS}(t_n)$ denotes the effective value of the AE signal sampled by the recording system at the time t_n within the interval $\langle t_1, t_2 \rangle$.

According to formula (3.1), three descriptors : U_{tA}, U_{tB} and U_{tC} were analysed. The first one included the totalized samples of U $_{RMS}$ at the first 8 ms of the punching process, the second one included the samples at the time beginning in 8 ms and cancelling in 16 ms of the punching process and the third one included the samples at the time beginning in 16 ms and cancelling in 24 ms. Thus U_{tA}, U_{tB} and U_{tC} were proportional to the average value of U_{RMS} measured during the periods stated above.

To describe the changes in AE signal intensity caused by modifications of punching conditions the following configuration schemes were investigated:

1. A punch press is operating but the razors do not penetrate the feedstock (the reference intensity of AE signal).
2. One small conical razor is punching the feedstock.
3. Two small conical razors are punching the feedstock.
4. All the small conical razors are punching the feedstock and one of big squared razors is missing.
5. All the small conical razors and all the big squared razors are punching the feedstock.

The values of U_{tA}, U_{tB} and U_{tC}, the average of 6 recorded waveforms together with the value of calculated standard deviations for all experimental schemes described above are presented in Table 1. Typical records of the AE signal for all 5 schemes described above are shown in Fig. 10. The difference between the background signal level, marked with diamonds and the

TABLE 1. The values of U_{tA}, U_{tB} and U_{tC}, the average of 6 recorded waveforms with the value of calculated standard deviations (σ) for all experimental schemes.

Scheme description	U_{tA} [mV]	$\sigma(U_{tA})$ [%]	U_{tB} [mV]	$\sigma(U_{tB})$ [%]	U_{tC} [mV]	$\sigma(U_{tC})$ [%]
the background intensity of AE signal	229	13	289	13	818	24
one small conical razor operating	242	14	327	11	1409	86
two small conical razors operating	498	61	566	36	912	26
one big squared razor missing	2182	10	2838	30	3802	53
all razors in use	8588	11	10824	7	5987	29

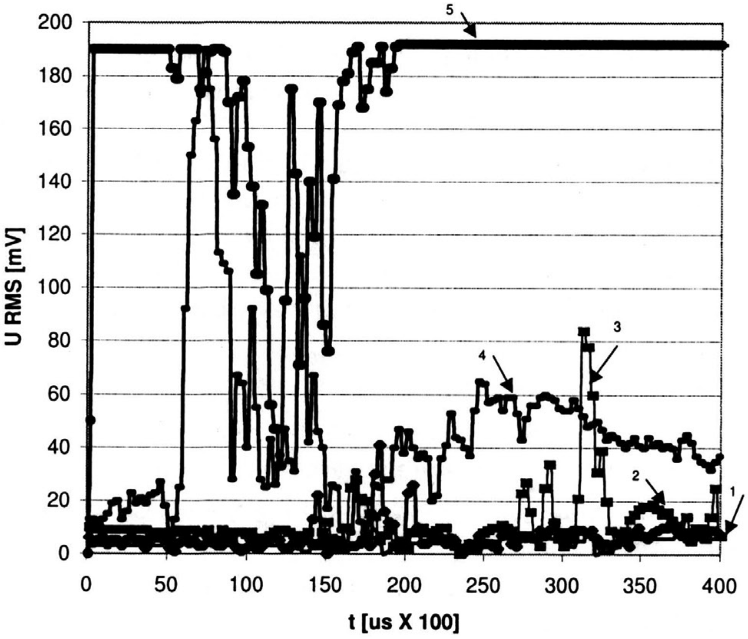

FIGURE 10. Typical records of the AE signal evoked by the punching for all five schemes described in the paper. The time division at the horizontal axis is 5 miliseconds (5000 microseconds).

signal generated by the small razor, marked with small squares is hard to distinguish. As it will be shown on later these levels differ in 10% within the initial part of the waveform. The work of the two small razors, marked by big squares and the work of the all small razors, marked by small circles are easy to recognize. All the experiments performed under the same conditions. A special care was focused on proper feeding the punch press with the brass band. It has to be fixed to the base of the machine. Friction processes generated by the loose sections of the band were significant sources of background noise. However, this problem doesn't appear under real industrial conditions because special tape dispensers are in use there.

4. Discussion of results

Our investigations proved that AE sensor placed on brass tape feedstock processed by the punch is capable of monitoring a real punching process. AE signal, amplified and filtered in a separate device can be transmitted directly to the computer via sound line input. An application of concurrent process supervising methods is difficult because of continuous process character and of high punch cycles rate per second used in pracise. As it can be seen in Fig. 9., the waveforms recorded at the operation of progressive punch workpiece present complicated shape what is caused by a large number of AE sources working simultaneously. However, the application of proposed AE descriptors is reasonable to detect the changes in AE signal intensity caused by modifications of punching conditions.

Among these descriptors, the value of U_{tA} and U_{tB} increases together with the increasing number of razors in use. The dispersion of registered results remains at acceptable level. The values calculated for the third descriptor, U_{tC}, together with remarkably greater dispersion are less useful. Probably U_{tC} reflects the part of AE signal being the echoes after the end of the workpiece penetration period. Therefore, in our opinion, the described method can be used in industrial conditions.

References

1. B.S. KIM, Punch press monitoring with acoustic emisson (AE), Part 1: Signal characterization and stock hardness effects, *J. of Engineerng Materials and Technology*, Vol.105, pp.295-304, 1983.

2. A.J. WILCOX, D.R.H. BAGGS, B. SHIRVANI, Acoustc emission in press-working, *Records of Faculty of Engineering and Computer Technoogy University of Central England*, pp.295-303, 1990.

3. T. SKARE, P. THILDERKVIST, J. STAHL, Monitoring of friction processes by the means of acoustic emission measurements – deep drawing of sheet metal, *J. of Materials Processing Technology*, Vol.80-81(0), pp.263-272, Elsevier Publ., 1998.

4. M. MARCZAK, R. MARCZAK, Z. RANACHOWSKI, J. SENATORSKI, Application of acoustic emission method to determine the state of friction process of metal collaborating pairs – preliminary results, *The Archive of Mechanical Engineering*, Vol.XLVI, No.1, pp.80-84, Warsaw 1999.

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