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VIBRATION MEASUREMENT DURING MILLING BY ACOUSTIC EMISSION

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Abstract

Production processes are nowadays very much challenged by the continuous improvement of productivity, the reduction of energy and ecological burden and the pursuit of the highest possible economy of the whole process in general. In order to optimize any process, it is essential that the process quality can be measured, and its behaviour adjusted ideally "just in time". In the case of machining, vibration is a major problem. This phenomenon, which always accompanies machining and especially milling, has an essentially negative impact. The aim of this article is to present the possibility of measuring vibration both with special active tool grooves from SCHUNK and indirectly with the acoustic emission sensing method. The article also deals with the nature of vibration itself as well as the comparison of both methods and the validation of the results.

Keywords: Vibration; Vibration measurement; Acoustic emissions; Machining

1. Introduction

Nowadays, the machining industry is focusing on the use of multifunctional machining centres, where, together with a suitable monitoring system, it is possible to achieve a significant improvement in production efficiency. Machining processes are associated with deformation of the cutting tool and workpiece, which is caused by cutting forces, thermal effects and vibrations. Modern monitoring systems are used to monitor the measured characteristics of the machining process, collect and evaluate the data. This enables the machining process to be controlled retrospectively by adjusting the cutting conditions, e.g. cutting speed, feed rate or cooling medium supply. The monitoring system must therefore identify the actual cutting conditions during the production process via sensors. Reliable sensing systems coupled with signal processing techniques are required to monitor processes and extract useful information from the machining process. Based on the information obtained from the sensors, the adaptive control system must be able to handle a wide range of modifications to the machining process, from simple stopping of machining to advanced control. Vibration measurement is now quite common and can also be transferred to the machines. However, the whole device is very costly and requires specialized software and hardware. One simple method of measuring phenomena in machining, but also in other processes, is acoustic emission. This signal can be sensed relatively easily, even at greater distances from the cutting point, and it is possible to measure certain behaviours of the system with this signal.

The aim of this paper is to give answers to whether it would be possible to use the acoustic emission signal to evaluate vibrations during the machining process. Then to compare these signals with a commonly available active tool clamp which is used to measure vibration. This should make this monitoring of the machining process simpler and cheaper in the future. [2] [3] [10].

2. Acoustic emissions in the machining process

Acoustic emission (AE) is a physical phenomenon in which stored energy is released in a material in the form of transient stress waves due to dynamic processes. These dynamic processes are stimulated by internal or external forces. The waves propagate in the material from the source towards the surface. Due to the passage of the stress wave, part of the energy is converted into heat, part of the energy is returned to the material and part of the energy induces a so-called Rayleigh wave at the surface. The waves that are on the surface are then suitable for capture by a sensor and converted into an electrical signal, which we call an emission signal. The resulting amplitude is on the order of micrometres. The waves generated by acoustic emission range in frequency from the lowest (0,1-100 Hz) to high frequencies (up to 10 MHz), which can be observed in lattice faults or fracture propagation due to mechanical breaking. Figure 1 shows the principle of measuring and evaluating acoustic emission [2] [3] [7].

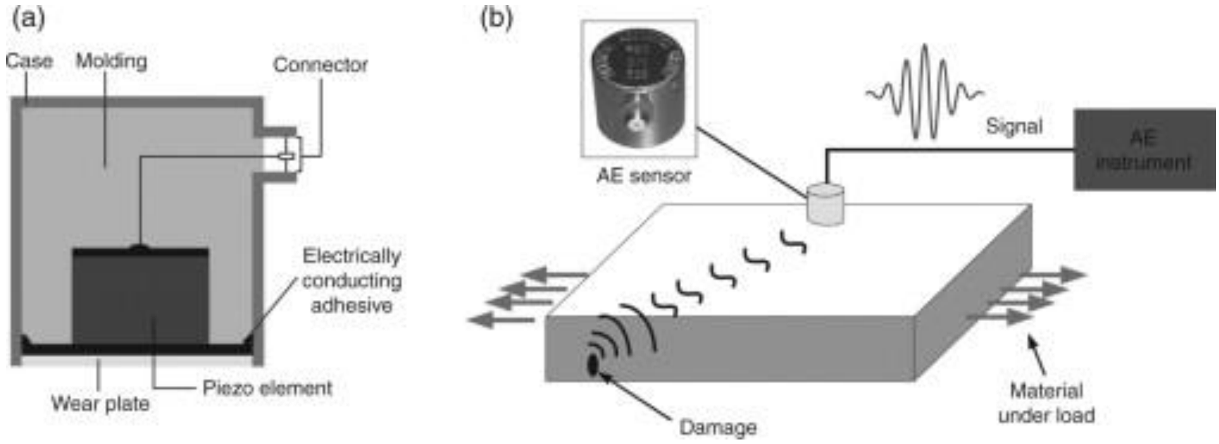

Fig. 1. The principle of acoustic emission [1]

In the machining process, AE is mainly used for comprehensive tool wear monitoring. Sometimes as a warning of complete tool destruction by micro cracks in the tool that cause AE signals. This is used for quality monitoring of tool wear or process control. Tool wear changes the contact area between the tool and the workpiece and thus the intensity of AE. When tool wear or catastrophic tool failure occurs, the AE signal changes during cutting or, in the case of tool breakage, shows dramatic peaks from the energy released during breakage [2] [3] [8].

The benefits of acoustic emission include:

- High sensitivity
- Early detection of defects, cracks, breaks, etc.
- Real-time monitoring
- Cost reduction
- No need to scan the entire structural surface.

The disadvantage of acoustic emission is that we do not know the exact cause of the acoustic wave, as the energy released is influenced by several factors such as the shape and surface of the body, the transmission path of the wave (acoustic wave propagation function) given by the structure and homogeneity of the material [2] [3] [8]. The AE signal obtained usually characterizes the number of memory waves in a certain amplitude range released per unit time. AE signals are distinguished based on their sources into continuous (continuous) and impulsive (discontinuous). Continuous signals are associated with the area in the primary region where chip shearing occurs and then at the wear face and tool back. In contrast, impulsive signals are caused by cracks in the material, chip breakage or impact, or breakage of the tool edge [2] [8].

2.1. Sources of AE in the machining process

During machining, acoustic emission (AE) is mainly caused by plastic-mechanical processes in the form of cracks, chip evacuation and surface friction. These sources are illustrated in the following figure [3] [4].

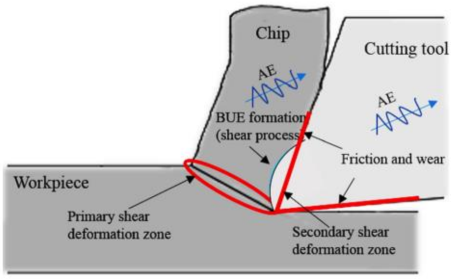

Fig. 2. AE sources in the Machining Process [11]

Each of these sources is manifested in a specific frequency band and has a specific intensity. The AE signal arising from plastic deformation is continuous in nature, while in other cases the signal is discontinuous and more energetic. One of the phenomena that limits the use of AE is the attenuation properties of the material. This means that the same phenomenon in different materials can result in different character of acoustic emission. It is therefore necessary to make a sufficient number of comparative measurements for the accuracy of the measurements to be meaningful. AE is therefore particularly suitable for series production where a large amount of measurement data can be used to determine exactly what a given AE characteristic means. Another disadvantage is also the scattering and reflection of the voltage waves, which is given by the size of the measured body [3] [4].

2.2. Acoustic emission measurement

Multiple sensors and multi-channel measurement systems are used to measure acoustic emissions. The acoustic emission sensors, which are distributed on the structure, form a measurement network. This network allows the location of the origin of the emission activity to be located. The localisation is based on the time difference of the arrival of elastic waves of acoustic emission at the different sensors of the network [5].

Linear localization – the arrival of elastic waves at two sensors is used to determine the location of the emission event. The source lies at the junction of these sensors [5].

Area localization – requires the arrival of elastic waves to at least three sensors. The location of the emission event can be determined if we know the time differences of the arrival of the waves at each sensor and the speed of propagation of the acoustic waves [5].

The design of the sensors is adapted to their use, so there are many types and types of sensors. In practice, piezoelectric sensors are the most used. In the design of piezoelectric sensors, the piezoelectric effect is used, where inside some crystalline dielectrics, due to mechanical deformations, an electrical polarization is created, which causes apparent charges on the surface, which can bind or release real charges in the attached electrodes. If the mechanical stresses disappear, the dielectric returns to its original state [6][10].

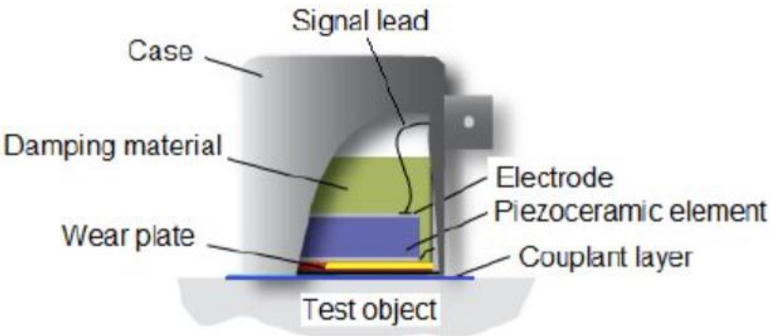

Fig. 3. Piezoelectric AE sensor [6]

Acoustic emission sensors can be divided into:

- according to the frequency range of the measured signals:
- low frequency sensors 0 Hz ... 1 kHz
- mid-frequency sensors 1 kHz ... 100 kHz
- acoustic emission sensors 100 kHz ... 2 000 kHz

According to the permissible operating temperatures of the sensors:

- standard temperature range
- extended operating temperature range
- high temperature sensors

According to the connection method to the measured object:

- direct bonding of the sensor to the surface
- by magnetic holder
- screw connection (external or internal thread on the sensor)
- by means of a welded rod waveguide
- belt clip (on tubes)

Due to the nature of the AE monitoring process, it is necessary to place the sensors as close as possible to the machining point. For operations such as turning, where the main rotational motion is performed by the workpiece, it is necessary to place the AE sensors directly on the tool body or tool clamp. In contrast, for operations where the tool performs the main rotary motion (e.g., milling, drilling), the encoders are placed on the workpiece and the toolholder. The sensors must therefore be resistant to coolant, dirt, flying chips as well as mechanical, electromagnetic and thermal effects. They must not restrict the working space and cutting parameters [5] [7] [8].

2.3. AE signal modification and evaluation

When measuring AE under industrial conditions, acoustic noise/noise present at lower frequencies (below 30-50 kHz) must also be considered. It is therefore necessary to ensure that it is filtered out. This can be done in two ways. Either directly at the time of measurement by appropriate sensor selection, using a filter on the preamplifier and on the AE measuring unit, or by digital processing and filtering of the measured data [3] [4] [6]. The aim of acoustic emission evaluation is to detect the source of these emissions during the measurement. The basic principle is to evaluate the acoustic sources when loading the measured objects at or above the nominal load value, finding and characterizing the impulses, their temporal localization, oscillation frequency, amplitude, and phase. This information is indicative of the sudden emission of elastic energy generated within the material. Obtaining such physical parameters from AE signals is one of the most common problems in its processing. This is since these signals are non-stationary and often contain overlapping transitions, and their waveforms and the time at which they occur are unknown and involve variations in terms of time and frequency. Often such events are partially overlapping in time or are subject to noise [3] [4] [6] [9]

The basic parameters in acoustic signal evaluation include: [9]

- *Reference count*: the number of times the amplitude of the signal crosses a threshold line,
- *AE events*: the micro-structural displacement that leads to the generation of pro-elastic waves in the material under load and stress,
- *Rise time*: the time taken to reach the maximum amplitude from the first time the signal crosses the boundary,
- *RMS voltage*: the voltage that defines the intensity of the AE signal

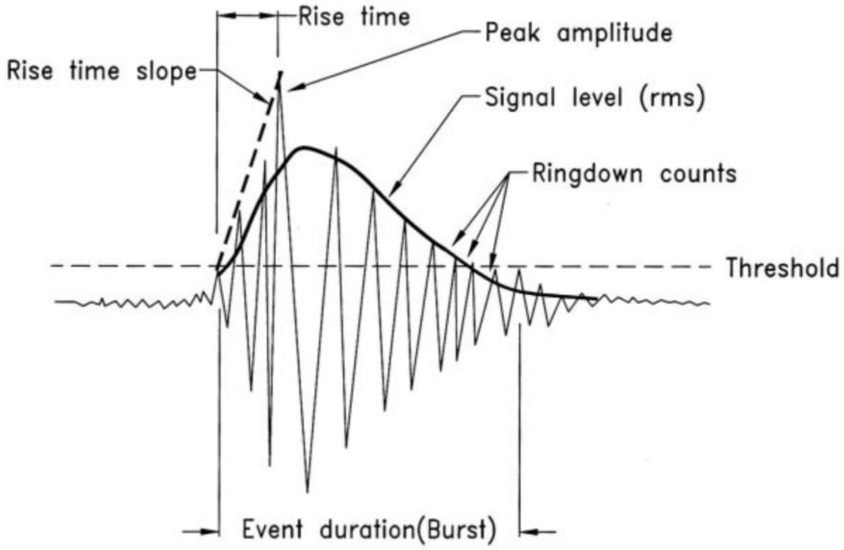

Fig. 4. Characteristics of AE signal [9]

3. Experiment

Acoustic emission has interesting potential for measuring various processes during the machining process. For this reason, an experiment was carried out to experimentally verify the possibility of measuring vibrations in the machining process using AE. This experiment was carried out on the milling of aluminium alloy AW EN 7075, where only sideways machining of the tool occurred. In order to evaluate whether the AE signal could be used in any way for vibration measurement, it was necessary to perform a retention measurement with an already validated device. For this reason, an active toolholder with integrated axis vibration measurement from SCHUNK, called iTENDO², was used. This fixture allows vibration to be measured directly on the tool, during the machining process. This signal is transmitted to a display device where the signal can be evaluated and processed retrospectively.

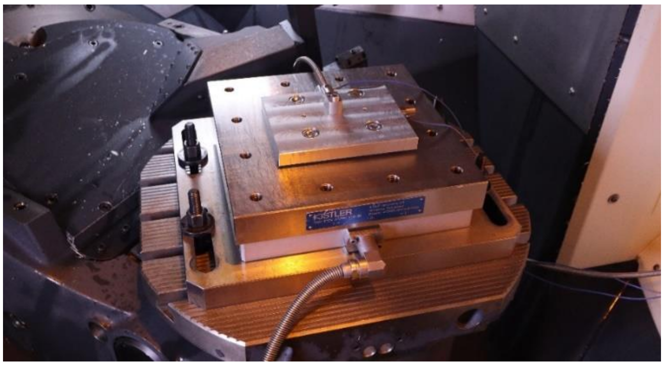

Fig. 5. Setting up the aperture in the machine

Thanks to this, it was possible to compare the acquired signals and evaluate with what accuracy it is possible to monitor vibrations as a very important phenomenon of the machining process using AE. The experiment was carried out under the following conditions, see Table 1.

Sample number	Cutting speed [m/min]	Feed per tooth [mm/tooth]	Sidestep [mm]	Depth of cut [mm]
1	250	0,01	0,5	15
2	450	0,073	5	15
3	425	0,065	0,2	15
4	425	0,065	0,2	15
5	450	0,073	0,2	15

Table 1. Conditions of experiment

The measurements were carried out according to the scheme under variations of different conditions, as shown in Table 1. In the case of AE, the recording was realized by means of an amplifier and a measuring card into a measuring PC and evaluated directly there. In the case of the active iTENDO² fixture, the recording was transmitted wirelessly to the connected tablet and then exported from there. The data recording from the measuring PC to the active iTENDO² fixture can be seen in Figure 10.

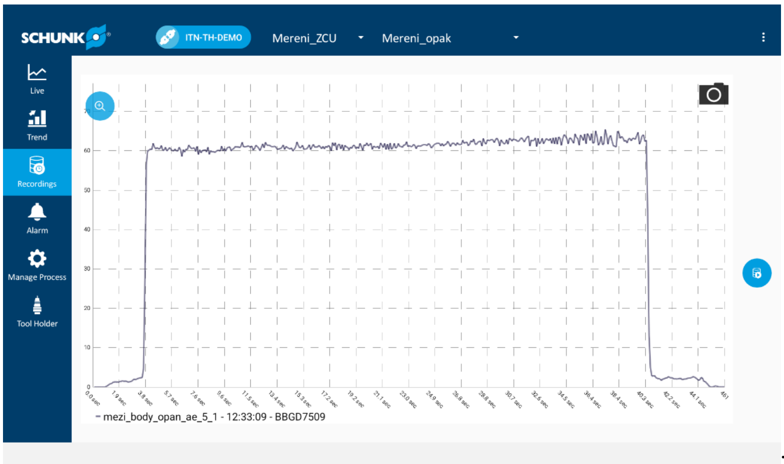

Fig. 6. Data recording from the measuring software from the active tool holder iTENDO²

The result of this experiment is a significant match between the AE outputs and the vibrations sensed by the iTENDO² active fixture. Although the two outputs are in different units, it is evident that the nature of the data is very similar, both at lower cutting conditions and at higher conditions.

The individual outputs can be seen in the figures below. Here, especially at the beginning of the measurement and at the end, there is still a slight difference in the progress of the two functions, but this difference is due to the different starting point for the two systems. If this effect is filtered out the agreement of the resulting functions is very good.

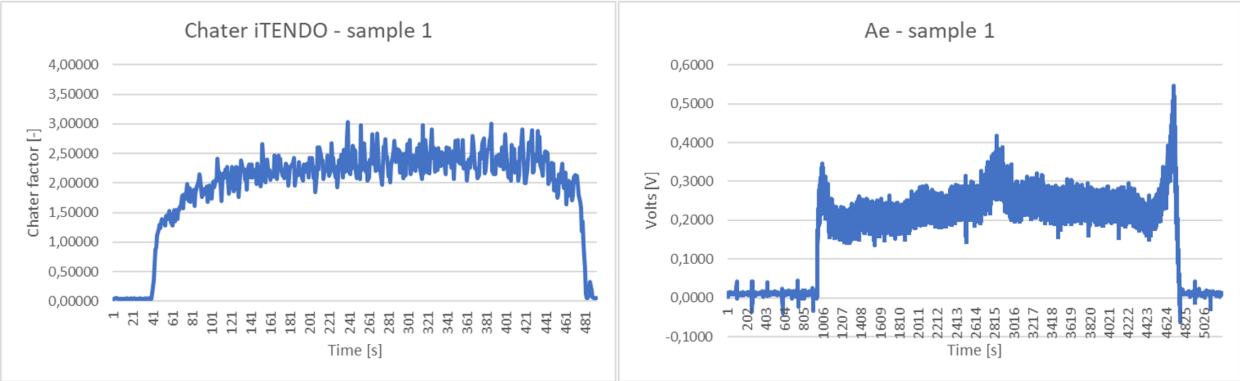

Fig. 7. Comparison of the resulting signal functions – sample 1

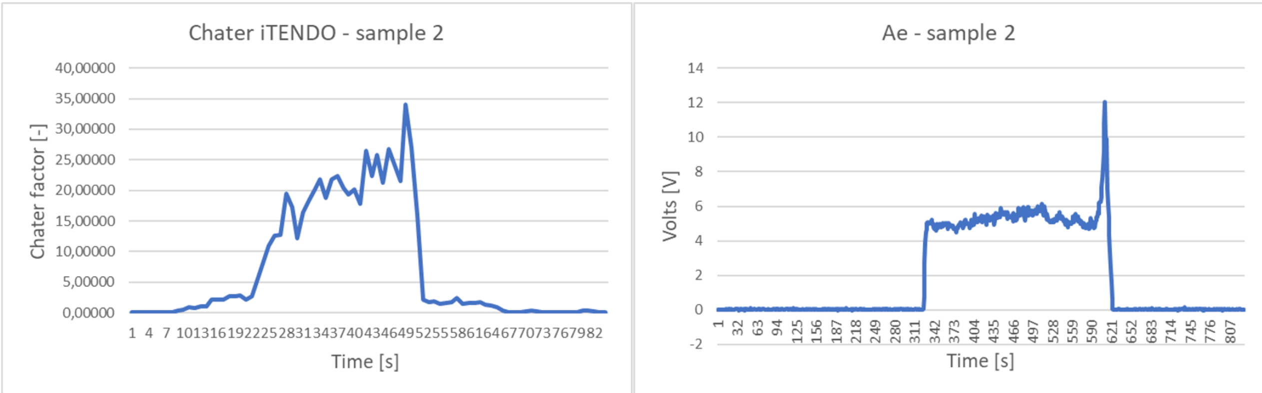

Fig. 8. Comparison of the resulting signal functions – sample 2

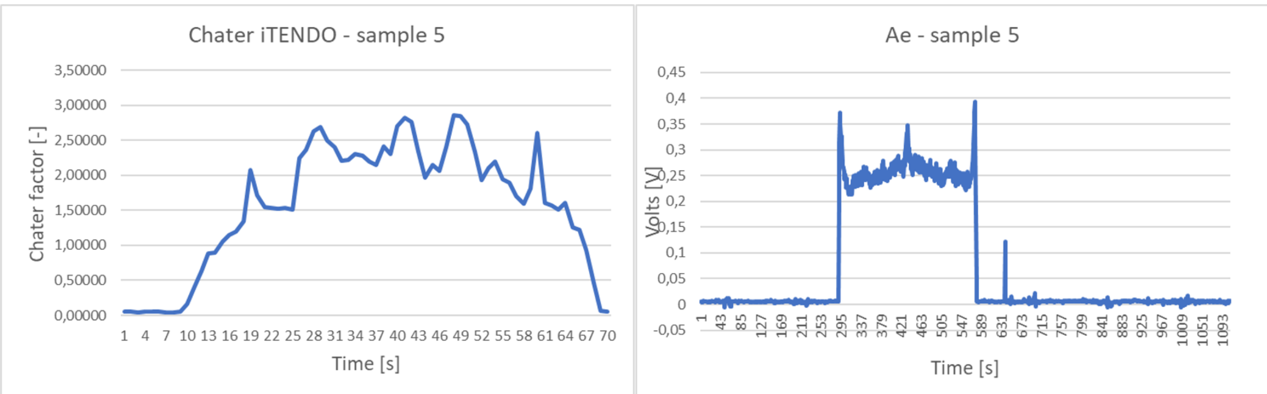

Fig. 9. Comparison of the resulting signal functions – sample 5

4. Conclusion

As a result of the whole experiment, it is found that vibration monitoring by acoustic emission can be used for this type of machining operation. The AE signal corresponds very well with the measured data from the active toolholder.

This experimental result is very interesting both from an academic point of view, where it gives further scope for a much greater validation of the results obtained, both on a variety of operations, and with a much more thorough evaluation methodology, such as DoE. And at the same time, it is a very good result for deployment in a real machining process. Here, the AE measurement system is very suitable both in terms of installation and sensor size, which allows deployment in many practical applications. Here, however, further measurements are first required, especially with respect to vibration attenuation versus the position of the encoder in the machine space and other variables.

Overall, the whole concept can be evaluated very positively as it has fulfilled expectations and at the same time opened further possibilities for research into the subject, which will be continued subsequently. In the future it will be advisable to include other variables monitored during the machining process in the evaluation and to try to find correlations between other phenomena.

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