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VIBRATION MEASUREMENT AND ANALYSIS OF A FRICTION STIR WELDING PROCESS[7]

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Abstract:

The paper presents a study of the vibration of a friction stir welding process. The acceleration is measured in the time area, and the spectrograms are obtained with the help of the Fast Fourier Transform algorithm. The amplitudes and frequencies of the vibration harmonics are determined. Also, the sources of this harmonics are localized.

Keywords: *Friction Stir Welding, Vibration Measurement, Vibration Analysis, Fast Fourier Transform, Time-diagrams, Spectrograms*

INTRODUCTION

Friction stir welding (FSW) is patented by The Welding Institute (TWI), United Kingdom in 1991 (Thomas et al., 1991). This is a process of joining parts by mixing the materials in a heated plastic state below the melting temperature (Vilaça P. & Thomas W., 2012). For this purpose, a third body is used - a tool, that can be of different shapes and sizes (Ferdinandov N. & Gospodinov D., 2021). The tool material must be superior in strength and hardness to the welded parts.

The difficult weldability of aluminum and its weak mechanical characteristics, compared to the steel tools, make it the most used material for FSW. Aluminum 1050 is suitable for the study and deep understanding of the physical processes taking place during the FSW (Sato et al., 2005), (Masaki et al., 2008), (Gospodinov D. et al., 2021).

To realize the process, a suitable machine is needed to ensure the rotation of the tool, the feed and the working stroke. There is a wide variety of solutions related to machine provisioning. Some researchers use standard milling machines, others use CNC machines, and in industrial conditions specialized machines and equipment for FSW are used. In general cases, the vibrations in the machines during technological cutting processes are a negative phenomenon and are the subject of increased study (Dimitrov D., 2021). Regardless of the machines, the friction between the tool and the welded parts causes vibrations. Friction as a source of vibration is a complex phenomenon and is also the subject of interest of various authors (Popp K., 2005; Popov M., 2020).

In FSW, the vibrations continue to have a negative effect on the machine, but on some of the properties of the resulting welded joints, they have a positive effect. Rahmi M. and Abbasi M. (2017) create external vibrations in normal direction to the seam length and reported that this caused 45% reduction in grain sizes in the seam area and a 7% increase in the strength (Rahmi M., 2017). They observed that an increase in the frequency of vibration leads to an increase in the investigated characteristics. Bagheri B. et al. (2019) conduct a study of friction stir spot welding in the presence of two-frequency vibrations. They found that grains decreased by 35%. The mechanical properties improve as the vibration frequency increases. Fouladi S. et al. (2017) found that vibrations increase

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the strength and ductility of Al 5052 samples. The vibrations negatively affect the corrosion resistance, which decreases. They observed that for subsequent machining of the welded parts, more force is required. In recent years, a new technology of FSW has emerged – vibration assisted friction stir welding.

The established tendency to improve the mechanical properties of welded joints with increasing vibrations frequency argues the work of Muhammad M. and Wu C. (2019), who use ultrasonic vibration assisted friction stir welding.

Other authors look for the possibility to improve the effect of vibrations by combining them with cooling (Barooni O. et al.,2017; Abdollahzadeh A. et al., 2021).

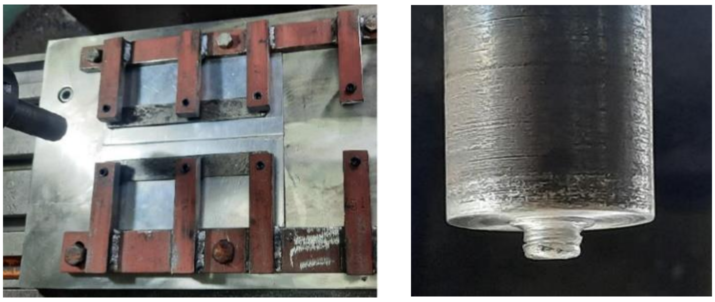
Some authors try to establish the relationship between vibrations and mechanical properties in the welded zone by numerical simulations. Montazerolghaem H. et al. (2011) use Simulink to determine the vibrations and compare the results with experimental ones. Bagheri B. et al., (2019) does a numerical simulation of friction stir spot welding using ABAQUS. They establish a good correlation between experimental and calculated results.

The performed review shows that studies of the influence of vibrations do not take into account the inherent vibrations of the machine on which the process is carried out. The focus falls on the modification of the additionally imported vibrations. *In this work, the authors set out to highlight the vibrations due to the machine and those whose origin is the friction between the tool and the welded parts.*

EXPOSITION

The experiment conduction and vibration signal processing

The friction stir welding is performed with the help of a universal milling machine FU 251. A fixture for holding the workpieces is designed and manufactured – Fig. 1a. The dimensions of the welded parts are 150x80x4 and the material is aluminum 1050. The experiments were conducted at spindle speed of 1000 rpm and feeding speed of 315 mm/min. The welding tool is presented on Fig. 1b. It has a smooth shoulder with a diameter of 22 mm and a cylindrical pin with a normal M6 thread and height 3.6 mm. The accelerometer is bolted to the plate – Fig. 2.



a) b)

Fig. 1. Fixture and tool (Gospodinov D. et al., 2021)

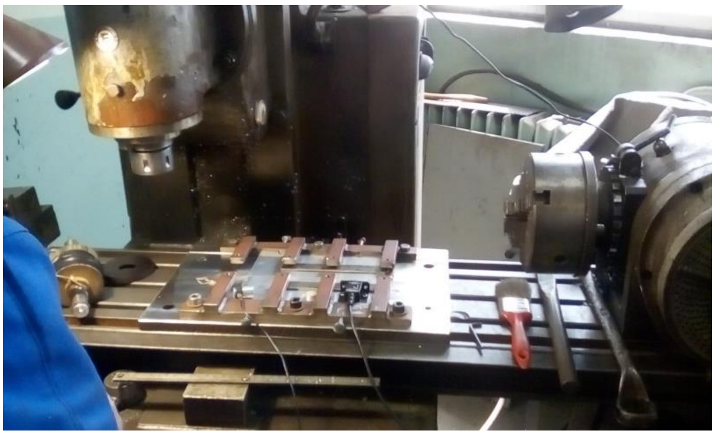


Fig. 2. "*3 Axis Vernier Accelerometer*" is bolted to the plate

The vibrations are monitored in three directions: parallel to the welding joint, perpendicular to the welding joint, and in direction vertical to the welding joint plate. The accelerometer used has linear response up to 100 Hz, and this limits the minimal time step to 0.01 s.

The values of the acceleration are measured with a step of 0.01 s and the time diagrams are created. For example, on Fig. 3 is shown the time-diagram of the vibration acceleration in the direction perpendicular to the welding.

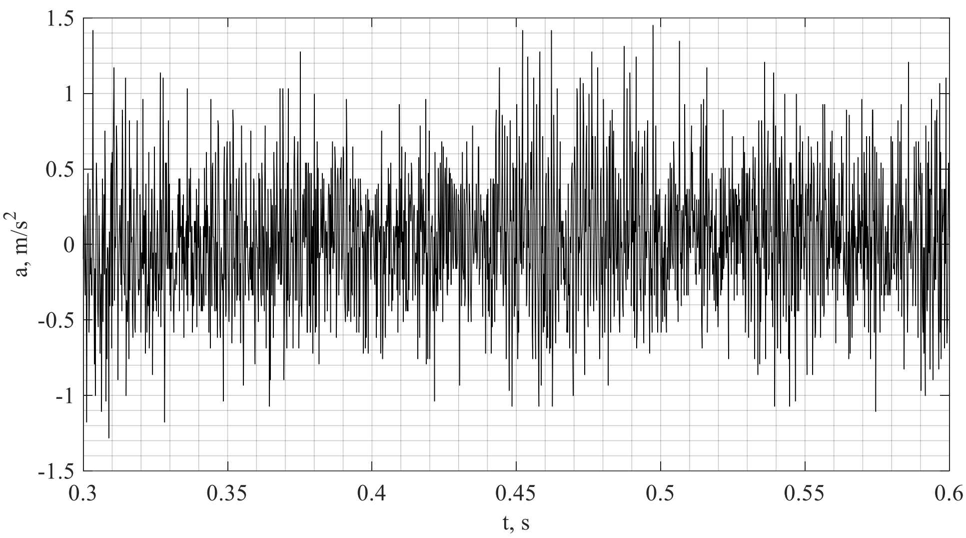


Fig. 3. Time-diagram of the vibration acceleration

The Nyquist theorem specifies, that a harmonic function in the time can be regenerated with no loss of information as long as it is sampled at a frequency greater than or equal to twice per cycle. So, the time-diagrams obtained, contains reliable information for vibration harmonics up to 50 Hz.

The processing to the frequency area is done through the Discrete Fourier Transform (DFT), using the Fast Fourier Transform (FFT) algorithm. The Fourier Transform (FT) separates a function into an alternate representation, characterized by the sine and cosine functions of varying frequencies. The FT shows that any waveform can be re-written as the sum of harmonics. If $a(t)$ is the acceleration in function of the time, then the acceleration in function of the frequency $a(f)$, can be obtained by:

$$a(f) = \int_{-\infty}^{+\infty} a(t)\ e^{-i\,2\pi\,f\,t}\ dt \qquad (1)$$

For discrete waveform with *N* points, this becomes to the DTF:

$$a(f) = \sum_{j=1}^{N-1} a(j)\ e^{-i\,2\pi\,f\,j\,/\,N} \qquad (2)$$

In Eq. 2, one can note that each $a(f)$ requires a number of operations proportional to N. Since we need to compute different $a(f)$, it would appear that the DFT algorithm requires on the order of N^2 operations, which we denote as $O(N^2)$. There exists a computationally efficient algorithm for computing the DFT which is known as the Fast Fourier Transform (FFT). For sequences of lengths that are powers of two, the computational cost of computing the DFT using the FFT algorithm reduces from $O(N^2)$ to $O(N\ log_2 N)$. The FFT is functionally equivalent to the DFT, it simply achieves computational savings by exploiting symmetries in the definition of the DFT.

Results and discusions

The spectrograms of the acceleration in direction parallel to the welding joint are presented in Fig. 4. The top spectrogram is the acceleration in idle speed, i.e., this is the vibration of the universal milling machine used for the welding. One can see a major harmonic with frequency of about 17 Hz, and amplitude of 0.09 m/s^2. On the bottom spectrogram, one can see some additional pics, according to harmonics with amplitudes in the range of 0.03 to 0.05 m/s^2. The frequencies of these harmonics are approximate evenly distributed with a step of about 2 Hz in the measured frequency area from 0 to 50 Hz.

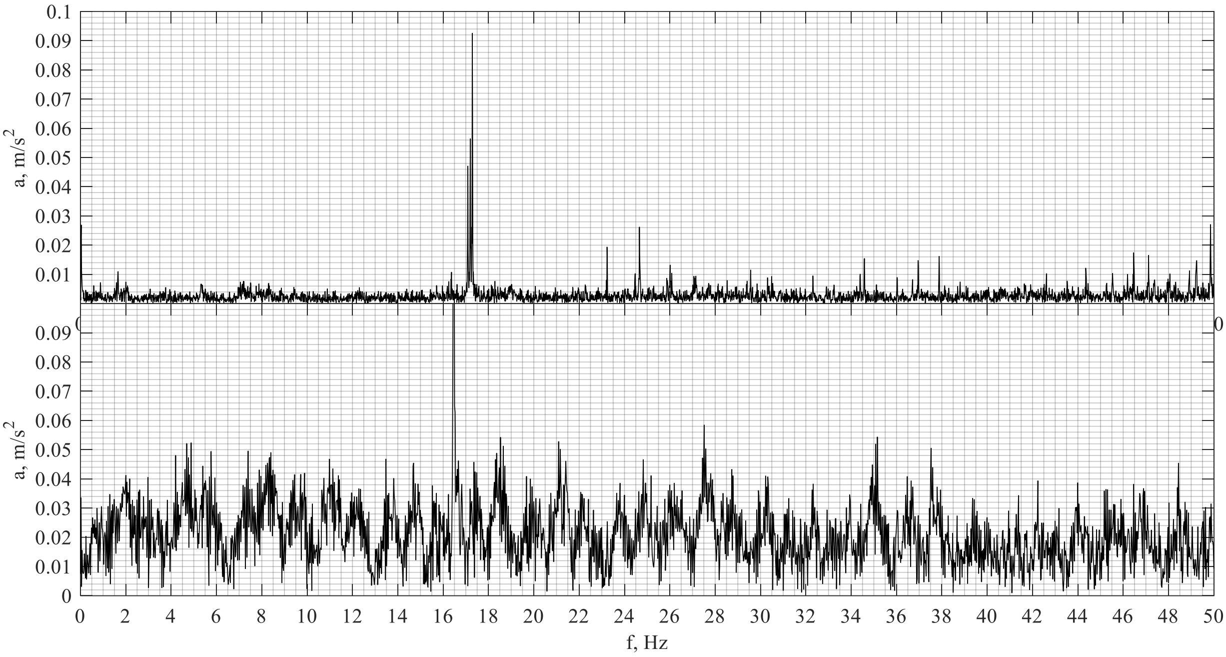


Fig. 4. Spectrograms of the acceleration in direction parallel to the welding joint: top – in idle speed, bottom – in friction stir welding process

The spectrograms of the acceleration in perpendicular and in vertical directions to the welding joint are presented on Fig 5 and Fig. 6. They indicate an analogical behavior, but the peaks are not so clearly expressed.

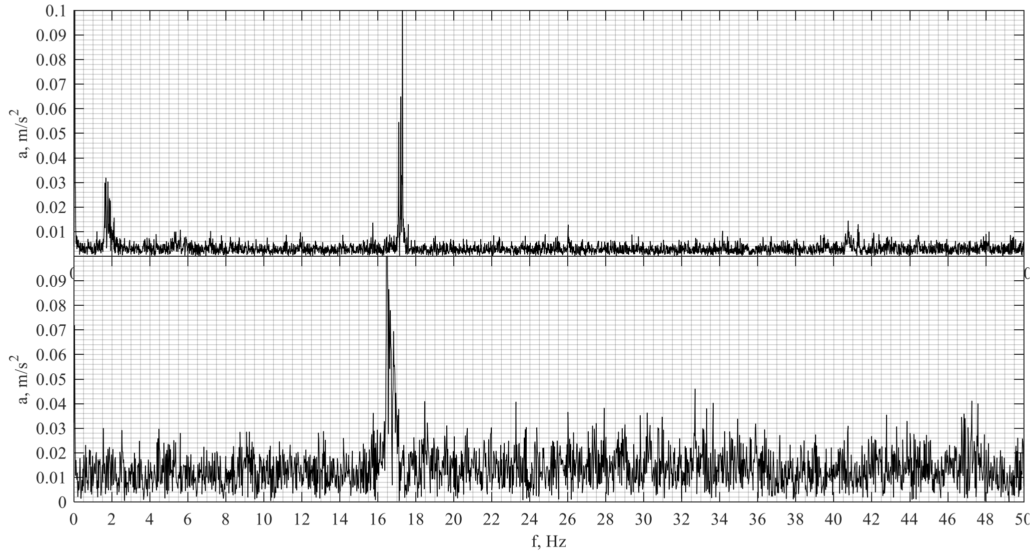


Fig. 5. Spectrograms of the acceleration in direction perpendicular to the welding joint: top – in idle speed, bottom – in friction stir welding process

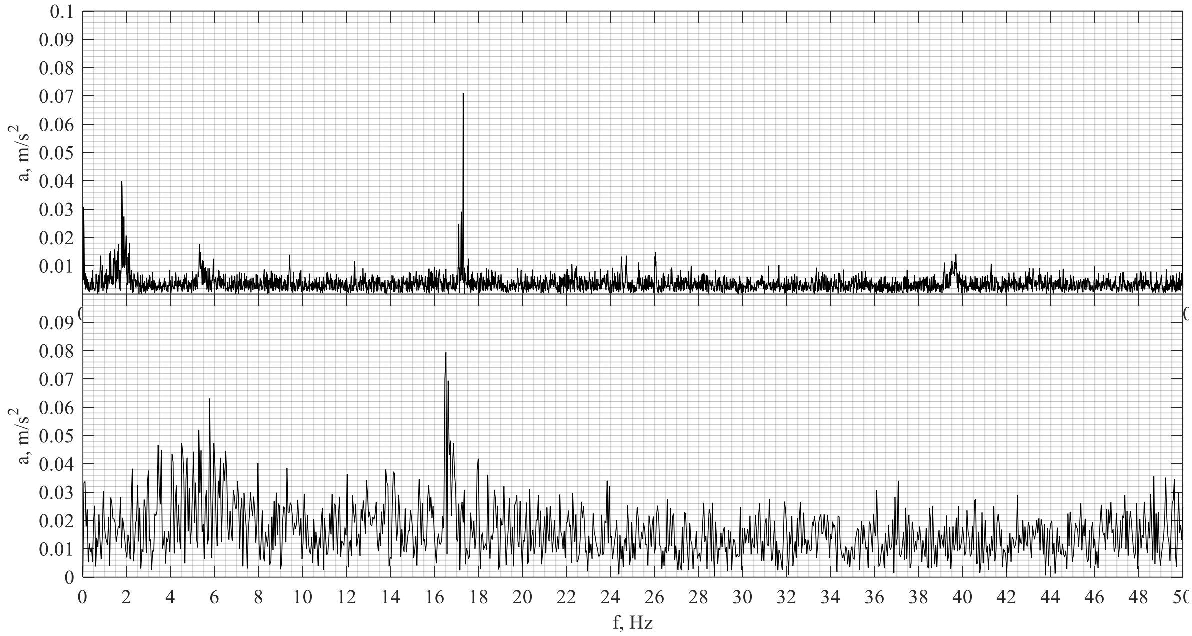


Fig. 6. Spectrograms of the acceleration in direction vertical to the welding joint: top – in idle speed, bottom – in friction stir welding process

CONCLUSIONS

The vibration acceleration of a friction stir welding is measured and analyzed in three directions: parallel, perpendicular, and vertical to the weld joint. It is necessary to continue the investigation. The analysis of the spectrograms should be refined. Some questions about the analysis remain to be clarified. Also, more experiments should be done with a sensor allowing measurement of higher frequencies and in different welding modes. After that, the obtained results will be used in the future studies to establish the influence of vibrations on the quality of welded joints.

It should be clarified what this weaker expression of the welding harmonics in Fig. 5 and Fig. 6 means. Also, it is necessary to study what is the reason for being a difference, albeit small, in the frequencies of the harmonic caused from the idle speed when the welding process occurs.

Further, it is of interest to research the influence of vibrations on the quality of welded joints. This can be explained in connection with the development of a software system for monitoring and controlling of vibrations. One of the suitable working environments for this is the graphical programming environment LabVIEW, which is widely used to develop automated research, validation, and production test systems.

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