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THE IMPACT OF ACCELEROMETER MOUNTING ON THE CORRECTNESS OF THE RESULTS OBTAINED IN NDT-TYPE TESTS

Summary. The paper attempts to evaluate the effect of acceleration sensor mounting on the recorded vibration time course. The study used a prepared model of a railroad rail and triaxial acceleration sensors. Three non-invasive methods of mounting the vibration acceleration transducers were selected for analysis: mounting with cyanoacrylate glue, mounting with a magnet, and mounting with wax. The information capacity of the signals was analyzed based on the recorded time waveforms, which totaled more than 90, and their vibration signals. The analysis compared both the basic parameters of the signals (maximum amplitudes and root mean square values) and a comprehensive analysis of the signals using the short-time Fourier transform method, as well as the wavelet transform. The results show significant differences in the recorded signal parameters depending on how the acceleration sensor is mounted, as well as the axis analyzed. The differences can negatively affect the correctness of the measurements made and falsify the picture of the real condition.

1. INTRODUCTION

The authors, who wanted to continue their scientific research focusing on the measurement of vibrations of various surfaces, encountered the problem of access to research facilities where they could perform tests in a controlled laboratory environment. Part of the research had to be carried out on the so-called living organism. This resulted in the exclusion of the use of accelerometers mounted to given surfaces in a permanent manner involving, for example, drilling a threaded hole. Moreover, vibration measurements of many technical objects are subject to limitations in the form of prohibition to interfere with the structure of the tested object. Most often, these restrictions is associated with strict safety rules for structures. Such a situation occurs, inter alia, during studies in which the analyzed objects are aircrafts [1, 2], bridges and viaducts [3-5], suspension systems, and drive systems of vehicles [6-8]. Strong restrictions on interference in the structure of the examined objects also apply to the area related to rail transport to the research related to the measurement of vibrations of railroad rails [9-13].

Vibration in rail vehicles is caused by the varying forces between the wheelsets of the vehicles running on the track, which can be traced back to geometrical irregularities in the track, discrete rail support in the form of sleepers, or the elastic characteristics of the railway tracks and the dynamic response in the train layout [14].

In the case of rail vibration, the issues are different from those of wheel vibration. The rail has different characteristics based on which the wave is supported and propagates along its length [15]. The roughness of the surface and the resulting unevenness on these two elements cause vibrations in the rail and wheel, and the vibrations' amplitudes depend on their dynamic properties. The resulting vibrations emit noise. This phenomenon is better illustrated by employing a model from D. Thompson's

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publication [16], which is an extension of Remington's work from the 1970s. This model was called "Track and Wheel Interaction Noise Software" (abbreviated as "TWINS") and is depicted in the graphic below:

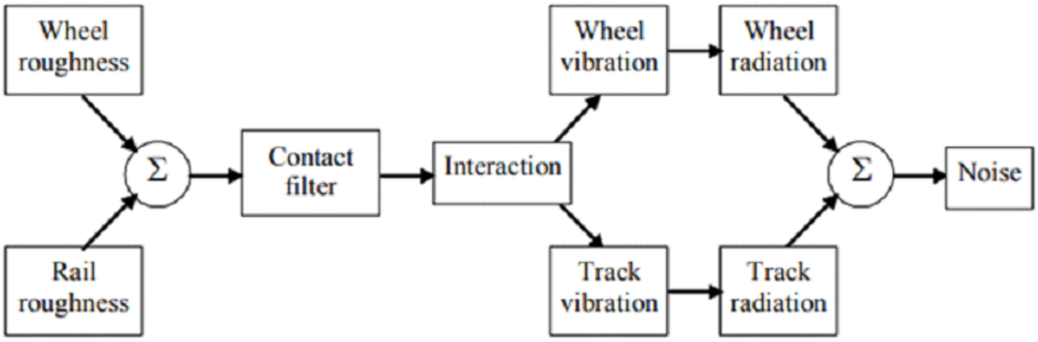

Fig. 1. Model of rolling noise generation [16]

The vibrations of rail means of transport are classified as vibrations propagated through the ground (parasseismic vibrations) of a random, non-stationary nature. Vibration in rail vehicles is caused by varying forces between wheelsets moving along the track, and it depends on a number of factors: geometrical irregularities in the track, discrete support of the rails in terms of sleepers, elastic properties of the rails, and the dynamic interaction in the wheel-rail system.

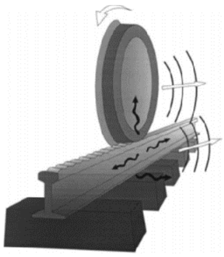

Fig. 2. Illustrative presentation of rolling sound generation considering wheel and rail roughness [17]

The issues associated with rail vibration are different from those associated with wheel vibration. The rail has dissimilar behavior in that the wave is sustained and propagates along its length. In summary, from a transport system operation point of view, the key sources of vibration include [14]:

- contact phenomena in the rail-wheel configuration,
- drive unit action,
- air oscillations during vehicle movement,
- the effects of imbalanced mechanical elements in the railway carriage.

Currently offered sets of accelerometers usually contain two mounting methods: a dedicated attached magnet and a mounting using a threaded connection. The threaded connection involves a permanent interference in the structure of the tested object, which often excludes such a solution. Meanwhile, using a magnet for mounting is ineffective when the object is composed of non-ferrous metals, metal alloys, or composite materials, which are commonly used in the construction of transportation means. Mounting with glue and beeswax is not directly advised, and there are no explicit instructions for their application with modern sensors. It does not change the fact that, despite the manufacturer's recommendations, this type of assembly is often used during measurements. Further information can be obtained by consulting guides and manuals from manufacturers of measuring instruments, such as Bruel and Kjaer or PCB Piezotronics. Nevertheless, even these publications contain no in-depth analysis of the pros and cons of employing various methods [18-20].

In the present research, an attempt was made to assess the impact of the type of accelerometer assembly on the trace and values of vibration signals. Experimental tests were carried out on a prepared stand of a complete railway rail. During the research, three sensors of vibration acceleration were mounted non-invasively: one with cyanoacrylate glue, one with wax, and one with a magnet. The obtained measurement results and their analysis show significant discrepancies between the tested methods of mounting vibration acceleration sensors.

2. MATERIALS AND METHODS

The worldwide scientific literature deals with the subject of attaching sensors to various surfaces from the point of view of the correctness of the measurements made and possibly avoiding the resulting measurement errors and limitations in the effectiveness of the accelerometer for a given mounting method [21]. It focuses mainly on patents, human measurements in the context of sports activities, and wireless connectivity.

If there is a need to mount a sensor permanently but making a threaded hole is impossible or undesirable, the sensor can be mounted with special washers. These washers are attached to the measuring point with a hard cyanoacrylate adhesive [21] or an adhesive from the epoxy resin group, as soft adhesives with much lower stiffness reduce the useful frequency range.

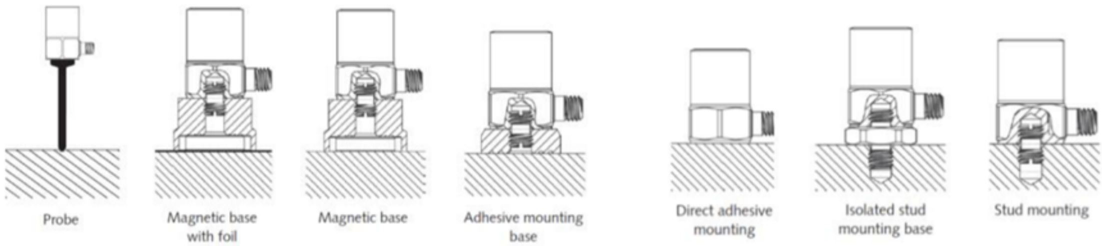

Fig. 3. Sensor mounting setups [22]

Mica washers or mounting screws made of insulating materials are used in order to electrically isolate the accelerometer casing from the measured object. This avoids problems related to the improper grounding of the measuring set. From the thick mica pad supplied with the accelerometer, a thin layer of mica is separated and placed between the sensor base and the test object. Such assembly also gives good results because the resonant frequency of the measuring accelerometer decreases only slightly to 28 kHz. If the measuring point is located on a flat magnetic surface, one can use a permanent magnet. However, this method limits the effective measurement of the sensor to a frequency of about 7 kHz and, thus, is not suitable for measurements above 2 kHz. Depending on the size of the sensor, the magnet can be used for acceleration levels up to 1000–2000 m/s^2. For quick measurements, one can use the handheld probe with the accelerometer on the top. The ease of measurement is offset by a large error due to the low stiffness of the system, and a good repeatability of the measurement should not be expected. A low-pass filter should be used to limit the measuring range to about 1 kHz. The authors of this article constructed a special laboratory stand (Fig. 4) to simulate measurements on a railroad.

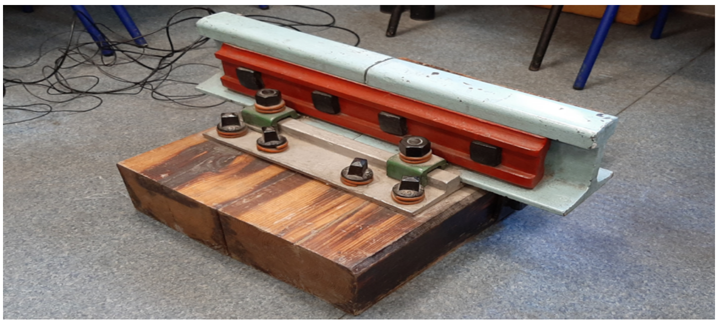

Fig. 4. Test stand – model of railroad used on sleeper beams

Bearing in mind the available mounting methods, the authors decided to use three of them, namely wax, cyanoacrylate glue, and a magnet. Two Dewesoft Sirius data acquisition modules connected in a synchronized manner were used to record the measurement signals (Fig. 5).

Table 1

Advantages and disadvantages of mounting accelerometers with glue [23]

	Wax	Glue	Magnet
Advantages	- comfortable to use - easy to store - immediate application without waiting for it to dry - simple de-molding	- curing at room temperature - rapid initial curing time - wide bandwidth and good temperature response range	- simple to apply - wide temperature range - good durability - size diversity
Disadvantages	- bounded top temperature band - bounded amplitude limit - bounded top frequency range	- need a solvent (Loctite™ X-NMS or equivalent) to break the adhesive bond before taking off the accelerometer - disassembly is time-consuming - hard to bond to rough surfaces	- limited bandwidth - caution required when applying the accelerometer/magnet to the installation area

Fig. 5. Synchronized Dewesoft Sirius modules

The following accelerometers were used for the measurements: 3x the Endevco 65-10R triaxial accelerometer with a sensitivity of 10 mV/g and the Dytran 5800B3 modal hammer with three different attachments. The sensors were mounted on the rail head on a clean and smooth surface, as shown in Fig. 6.

The delivered Dewesoft software was used to record the trace of vibration signals, as shown in Fig. 8 below. The analysis of the recorded signals was carried out using Matlab software version 2019b.

The mounted sensors were located at the edge of the rail, while the excitation with the modal hammer was located at three selected points on the rail head (6 cm, 15 cm, and 30 cm from the location of the sensors). Using an attached set of hammer tips with different hardness characteristics (a rubber tip made of plastic and made of a metal alloy) allowed us to change the input energy and obtain over 90 results; we selected those that had a significant impact on further scientific work.

3. RESEARCH RESULTS AND ANALYSIS

The recorded vibration signals show clear differences in their traces depending on the type of sensor fixing. The greatest differences in the results were observed in the X-axis, whose direction was parallel to the direction of excitation (Fig. 9).

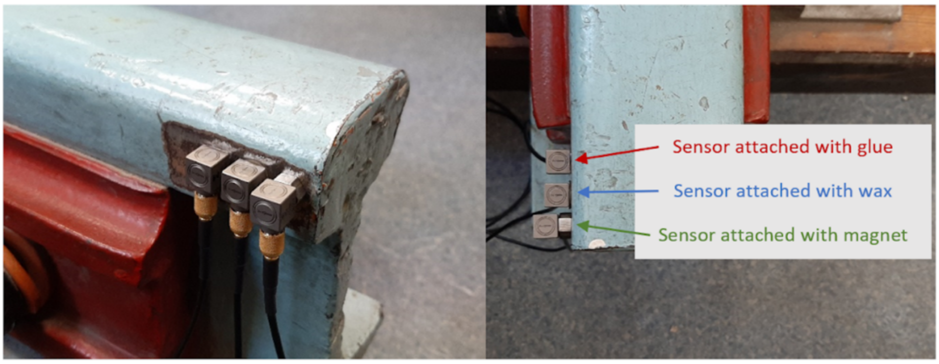

Fig. 6. Endevco accelerometers mounted on the cleaned side wall of the rail head

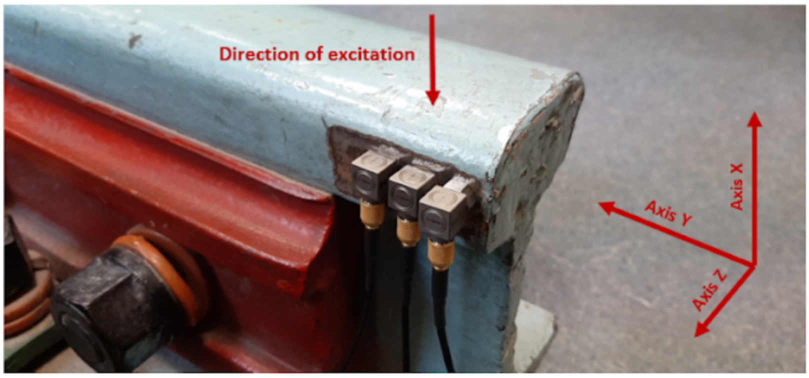

Fig. 7. Direction of orthogonal measurement axes of mounted acceleration sensors and the direction of excitation. X-axis – parallel to the excitation

Based on traces of vibration signals recorded during the measurements, root mean square (abbreviated as RMS) values and the values of the maximum amplitude (abbreviated as Pmax) were calculated. RMS values were calculated separately for every sensor and every axis for the whole recorded time trace. Selected results and their differences are presented in Figs. 10 and 11.

The percentage differences of the calculated RMS values in relation to the arithmetic mean calculated based on signals registered by the sensors mounted in the three tested ways were also calculated.

The calculated RMS and Pmax values of the recorded vibration signals, as well as the percentage change in RMS values, according to the type of sensor mounting (Fig. 10, 11), show noticeable differences in the above-mentioned calculated values in the case of system excitation. In the case of using a soft and medium hammer tip, the largest deviation of the RMS value from the average was recorded for the magnet-mounted sensor. However, in the case of a hard hammer tip, the largest deviation of the RMS value from the average was recorded for the sensor mounted with glue. This is most likely due to the lower damping value of the adhesive layer compared to the wax layer used. In the case of using a hard tip of the hammer (i.e., in the case of the excitation with the highest energy of the three excitations used), the installation of the sensor with the use of a magnet significantly lowered the RMS value of the recorded signal. This is due to the resonance of the magnet-mounted sensor, which was noticeable during the analysis of the waveforms of vibration signals.

4. CONCLUSIONS

In summary, one can notice significant differences in the time courses of the recorded signals depending on the assembly method. Differences in Pmax values reached up to several dozen percent and were the largest in the direction parallel to the axis of excitation. A strong tendency for the magnet to resonate for the strongest excitations was noticed; in the other cases, this tendency was not noticed.

There were also differences in RMS values of up to several dozen percent. In the case of the X-axis, the glue showed the highest anomalies for the strongest excitations.

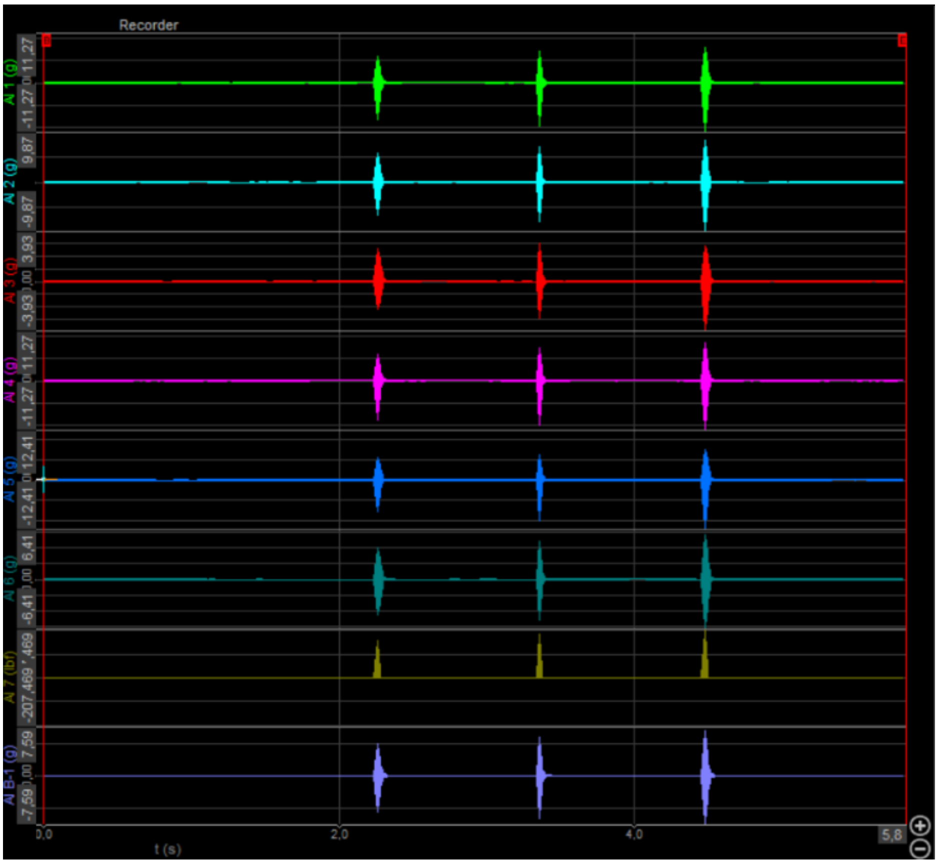

Fig. 8. Example of parallel recording of vibration signals in Dewesoft X3 firmware - user interface

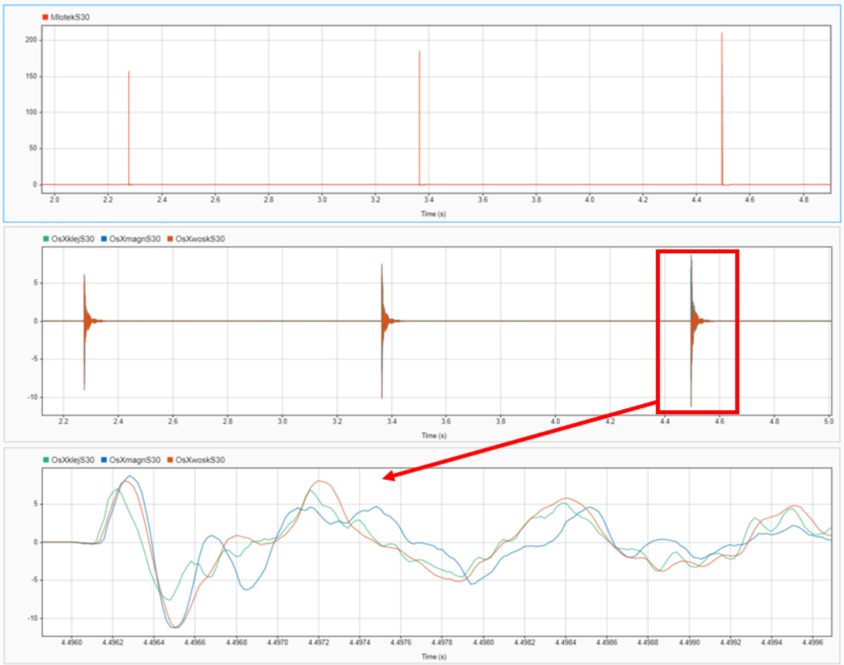

Fig. 9. The trace of the recorded vibration signals and the inductor signal shown in the MatLab software; X-axis-excitation with a medium tip of a modal hammer. From the top: inductor signal, time trace of sensors. Description of the markings: green - glue, blue - magnet, orange - wax

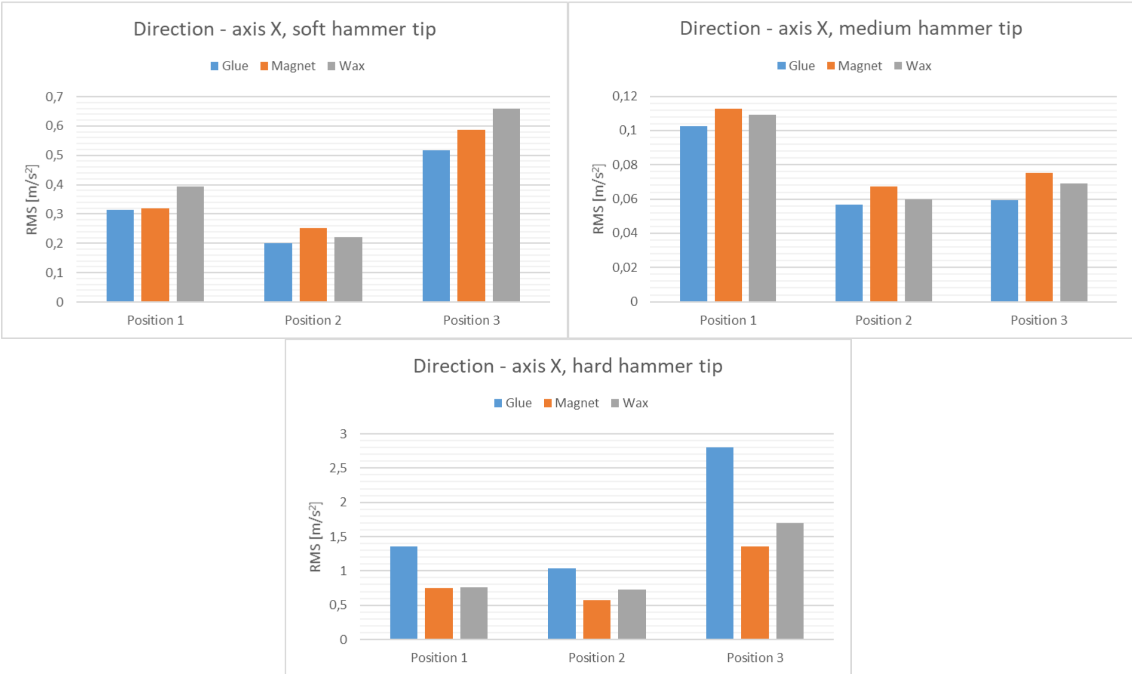

Fig. 10. RMS values of recorded signals in the direction of the X-axis

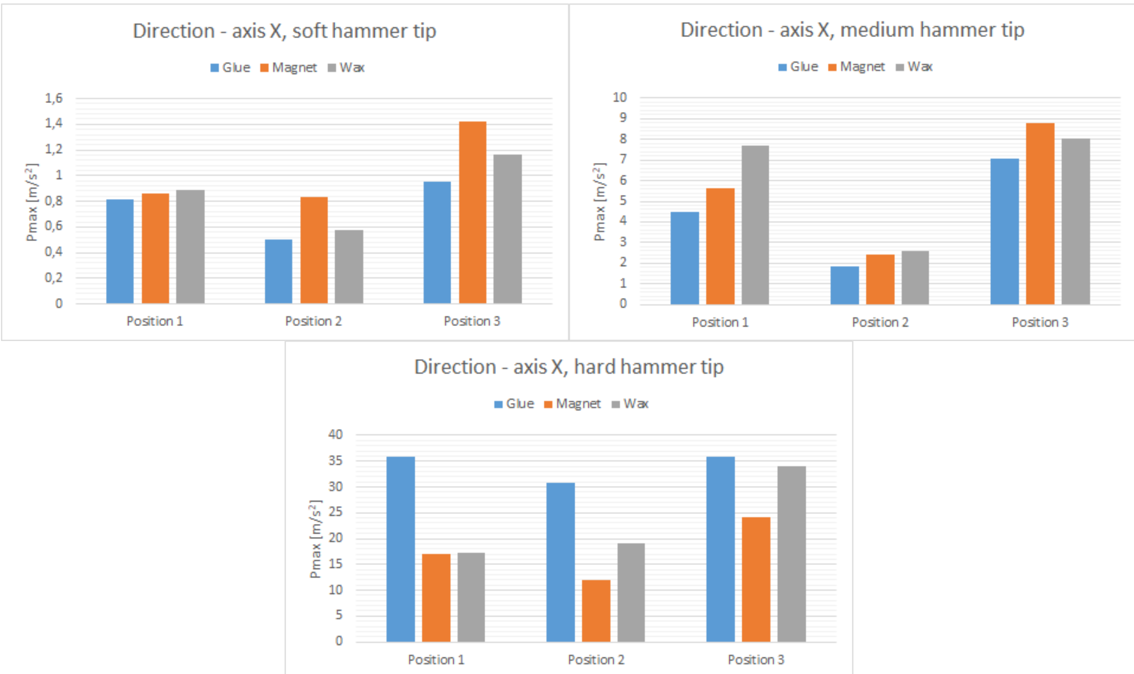

Fig. 11. Peak maximum of recorded signals in the direction of the X-axis

The most versatile fixture in this study was wax. There were no significant differences in the Pmax values for any of the analyzed study items. However, it should be noted that the tests were carried out at room temperature. This study indicates a new idea for future research. Namely, it indicates the need to develop the issue of the importance of glue and magnet mountings depending on the measurement axis; in the current research, the highest anomalies in the direction of the X-axis were noticed for these two fixings.

Table 2
RMS values in percentages of the investigated cases along the X-axis

RMS values in %; axis X				
		Type of tip		
		soft	medium	hard
Position 1	Glue	94,98	94,98	141,82
	Magnet	104,03	104,03	78,99
	Wax	100,99	100,99	79,19
Position 2	Glue	92,77	92,77	133,16
	Magnet	109,73	109,73	73,93
	Wax	97,50	97,50	92,91
Position 3	Glue	87,38	87,38	143,63
	Magnet	110,95	110,95	69,41
	Wax	101,67	101,67	86,97

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