Analysis of Vibration Transmission in an Air-Operated Demolition Hammer

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Abstract

The paper presents an analysis of vibrations of a ram, body and handle of a heavy, air-operated demolition hammer. The research was conducted in order to determine the character of dynamic inputs and resulting vibrations at the tool handle which were necessary to build a structural model of local influences on an operator taking the hammer design into account. The experiment was carried out on a test stand without participation of an operator, which guaranteed repeatability of measurements and elimination of ontogenetic characteristics. The displacements of selected structural elements of the tool were recorded by means of a camera and the accelerations at the handle were recorded by means of a standard measuring apparatus. The recorded signals were subjected to the spectral analysis and the short-time Fourier transform (STFT) using dedicated software in MATLAB environment.

Keywords: vibrations, dynamic inputs, short-time Fourier transform (STFT)

1. Introduction

As part of the conducted research an analysis of vibrations of a ram, body and handle of a heavy air-operated demolition hammer was performed. Such type of tools are commonly used e.g. in building industry, and their negative influence on an operator is well known [1, 4, 5]. The source of the harmful interaction are vibrations originating both in the driving unit and in the working process itself [2, 3].

The research was conducted in order to recognize vibration transmission in the hammer structure, to determine the main direction of their propagation, and to determine the character of dynamic inputs and resulting vibrations at the tool handle. The analysis of motion of individual parts of the tool is necessary for proper modeling and enables to interfere in the tool structure selectively. The recognition of the main direction of propagation enables to eliminate small influences and to limit the investigations to significant directional interactions. As a result of the performed analyses of vibrations at the tool handle it will be possible to create a structural model of a human being – tool object (with consideration and modeling of the hammer structure), which, in turn, will enable to model the influence of local vibrations on the tool operator. It should be remembered that the correct model of the system should include both the operator and the tool, because there exist mutual interactions between these elements [3, 6, 7].

2. Research object – test stand

Measurements were performed on a dedicated stand equipped with a holder to fix heavy hand-held tools (Fig. 1). The holder had been designed and made specially for the performed investigations in order to eliminate the participation of an operator, and hence to be independent of operator's ontogenetic characteristics (body mass, pressure force on the hammer, clamping force on the handle etc.). Foundation and positioning of the hammer in the test stand reflected its position during work in real environment. For the investigations a standard foundation in the form of an impact energy absorber was used – see Fig. 1.

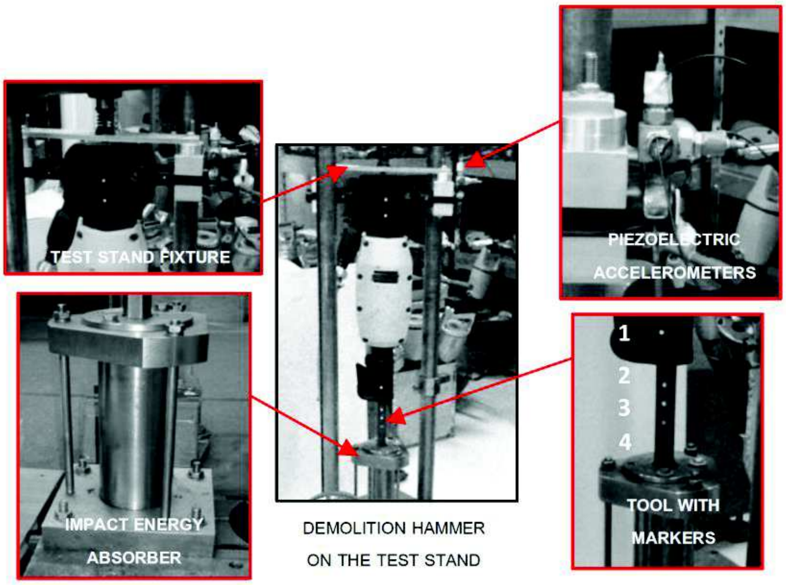

Figure 1. Research object in the test stand

As the research object a demolition hammer TEX 140 (Fig.1) was used, which is usually used in building industry for crushing asphalt, concrete, frozen soil etc.

3. Methodology of research

The research being the subject of this work was based on the analysis of the recordings of motions of the ram and casing of the investigated hammer and its handle, an operator is in contact with. For measurements of motion of the ram (and additionally the tool casing) a high-speed camera 1024 PCI [8] was used, which enabled to record displacements of vibrations. For this purpose several markers were placed on the tool, which motion was analyzed with the dedicated software. Additionally, three markers were placed on the ram to average its motion in time synchronously – Fig.1. The recordings enabled to identify the motion in the plane of the filmed picture.

During the test vibration accelerations of the handle in three perpendicular directions **X-Y-Z** were recorded as well. To do this, a measuring head with three piezoelectric absolute vibration accelerometers was used (Fig.1).

The results obtained from both methods enabled to determine vibrations at the handle and transmission of vibrations from the ram to the handle. As the measurements with the camera enabled to record the displacements, and with the accelerometers – vibration accelerations, the obtained results had to be subjected to an appropriate transformation and brought to one physical quantity. Integration of the acceleration signal was performed numerically after initial high-pass filtration.

4. Results

Figure 2 shows the comparison of displacements and spectra in **Z**-axis direction (the direction of work of the tool): for the hammer casing (point 1 – Fig.1) and the ram, computed by synchronous averaging of displacements of three points on the ram, marked as 2, 3 and 4 (Fig.1).

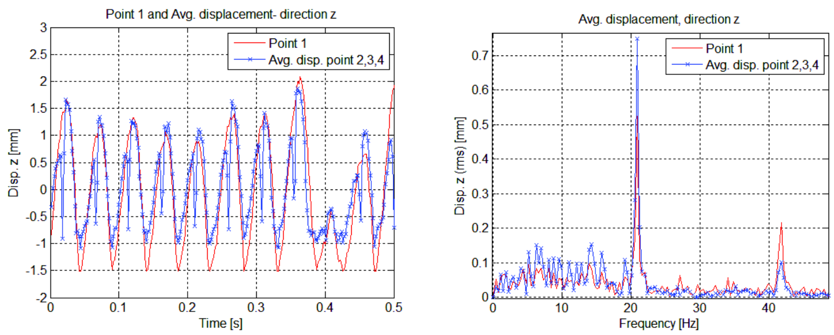

Figure 2. Displacements of the casing and the ram of the investigated air-operated hammer in time and frequency domains (enlarged sections)

In the range below 20 Hz and for the frequency of work of the tool (about 22 Hz) the tool casing vibrates generally with lower amplitudes than the ram. The differences are, however, not so big as one could have expected. One can say, that the amplitudes of displacements are comparable even for higher frequency ranges than those shown in the picture, which means that the casing of this hammer is not separated from the source. Moreover, as one can see, the vibrations of both elements are cophasic. A question may arise here, whether when building a dynamic model it is worthwhile to take both elements into consideration. This seems purposeless. Hence, in the case of the investigated tool, the model being created may be limited to a model with fewer degrees of freedom, taking the tool casing and the ram together into account.

Analyzing the motion of the casing at a measuring point placed near the ram (Fig. 3a) and the motion of the ram itself (Fig. 3b) in the **Y-Z** plane one can see, that these motions in the axis perpendicular to the impact direction are significant and cannot be omitted in the modeling of interactions of vibrations on the operator.

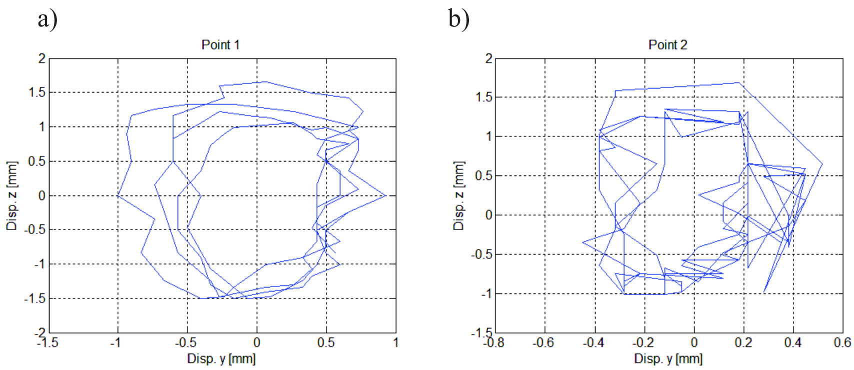

Figure 3. Movements of a selected point on the casing near the ram (Fig. a) and the ram itself in its middle point (Fig. b)

What is the most important this indicates the character of fixing the hammer in the test stand. At points placed at longer distance from the ram their lateral movements are not so important. This results from the fact, that the hammer is fixed well in its upper part, and that the collisions between the ram and the absorber are not central. To a degree this simulates real working conditions of the tool held by an operator. Hence, it seems to be important that forces perpendicular to the hammer axis are also taken into account in the model.

The performed analysis of vibrations of the hammer handle shows a reduction in vibration amplitudes (Fig. 4).

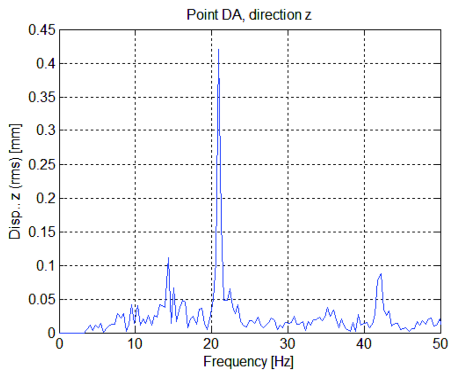

Figure 4. A section of an amplitude spectrum of vibration displacements of the handle. The result has been obtained by double integration of the recorded signals of vibration accelerations

In comparison to the amplitudes of the ram movements at the frequency of work of the tool (about 22 Hz) this drop equals almost 50%. Unfortunately it is not a lot when protection of the operator against excessive vibrations is considered.

To work out guidelines for building a proper model of the investigated air-operated hammer a time and frequency analysis of the signals was performed as well. The work of the hammer is non-stationary. This results at least from the fact that the collision process and possible fluctuations of working frequency of the tool are unrepeatable. That is why the short-time Fourier transform (STFT) was applied, which is defined as [9]:

$$X(f,\tau) = \int_{-\infty}^{\infty} w(t-\tau)x(t)e^{-i2\pi ft}dt, \tag{1}$$

where: t is time, $x(t)$ is the analyzed signal, w(t, τ) is a moving window function, τ is the shift of the window in time domain, f is frequency, and i is the imaginary unit.

Examples of results of such a time and frequency analysis are shown in Fig. 5.

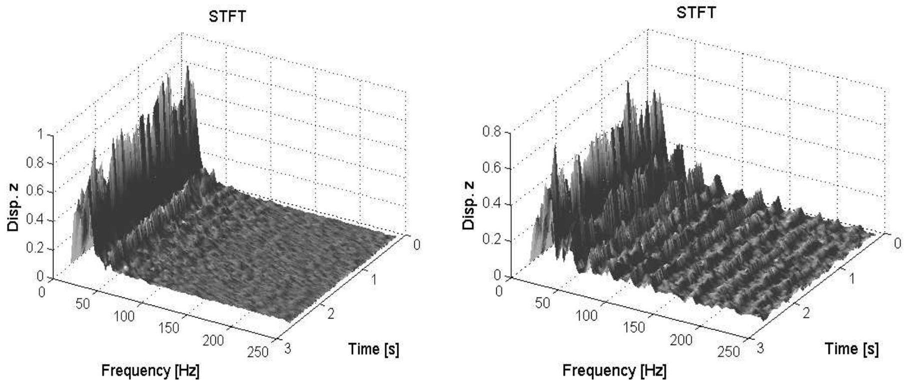

Figure 5. STFT analysis for two points. On the left: motion of a point on the casing near the ram; on the right: motion of a point on the ram near the casing

As it can be seen from the figures the input itself is non-stationary regarding amplitudes, the spectral composition of the signals, however, remains invariable. Moreover, it seems that only two or three components of the signal frequency should be essential in the analysis (see vibrations of the casing in Fig. 5), especially if the ram itself will be omitted in the model. This enables to define well the input in the dynamic model as regards both its average amplitude and its frequency composition. To assume, however, the input as a harmonic function with the working frequency of the ram, which sometimes is done, would be a too big simplification.

5. Conclusions

As a result of the conducted experimental research information enabling to build a dynamic model of the considered air-operated hammer was obtained. The results show that the modeling can be done by taking only the hammer casing and handle into account and omitting the ram. Additionally, it is essential to limit the complex frequency composition of the input to two or three harmonic frequencies. It also seems important to assume such a model, which takes also lateral input forces into account. This also determines the choice of the model of the operator of the hammer. Non-stationarity of the work of the hammer and, what follows, of the inputs may be taken into consideration by using the average amplitude of each component of the input or by modeling the system using stochastic differential equations.

Acknowledgments

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