

A NEW MEASUREMENT METHOD AND COMPARISON ANALYSIS OF MECHANICAL IMPEDANCE OF A TOOL-HAND SYSTEM

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(received April 30, 2005; accepted October 25, 2006)

In the paper the stand experimental studies of the hand-handle-tool system have been done with high speed camera application. The applied measurement devices and computer analysis of the data allowed for estimation of force and velocity of handle and finally for calculation of mechanical driving point impedance of the system.

Key words: tool-hand system, mechanical impedance, high speed camera.

1. Introduction

Mechanical driving point impedance is often used for depicting dynamical characteristics of biomechanical systems. It is defined as the ratio of the sinusoidal force applied at the chosen point of the human body and the velocity at the same point. Consider a sinusoidal driving force F that has a magnitude F_0 and an angular frequency ω . The force F can be written as:

$$F = F_0 e^{j\omega t}. \quad (1)$$

This force applied to a linear mechanical system results in the velocity V :

$$V = V_0 e^{j(\omega t + \varphi)}, \quad (2)$$

where V_0 is the magnitude of the velocity and φ is the phase angle between F and V . By definition, the mechanical impedance Z of the system (body) at the point of application of the force, called the driving point impedance, is given by:

$$Z = \frac{F}{V} \quad (3)$$

and is expressed in SI units as [Ns/m]. Impedance is a complex function of frequency ω , so it can be considered as a sum of real and imaginary components. The real component of the mechanical impedance represents the absorbed part of energy transmitted

from the source of vibration to the system. The imaginary component represents the “oscillatory” part of energy which is not absorbed by the system. The absorbed power can be considered as one of the important criteria depicting the influence of vibration on the human body. The results of the mechanical impedance measurements are quite often used in the international standards as the references for modeling human body the subjected to vibration. The biomechanical models of the human body, identified with the results of the mechanical impedance magnitude and phase, can be used for example in designing and optimization studies of vibration isolation systems such as handles and vehicle’s seats. The typical methods of measurements of mechanical impedance are shown in [3].

The most difficult problem in the mechanical impedance measurement is the correct estimation of the phase angle between F and V . To avoid significant errors, the applied method should base on the same kind of measurement chains for force and velocity. This approach is not easy to realize, because even in existing impedance heads there are different types of transducers and actuators for force and velocity measurements where in fact, signal coming from the accelerometer must be integrated. In the measurements of the mechanical impedance presented in this paper the authors applied an optical method that eliminates all the disadvantages related with the difficulties of the measurements of the phase angle between F and V .

2. Description of stand and method of measurements

The experimental investigations were conducted in the Laboratory of Dynamics of Mechanical Systems of the Cracow University of Technology. The electro-hydraulic shaker made by Heckert, controlled by sinusoidal signal in frequency range 0.5–200 [Hz], was used.

The vibrating control rod of the shaker, by intermediate of load indication bridle (Fig. 1), was fixed to a typical hand-held tool’s handle, kept by the standing operator with the angle of 120 [deg] between the upper arm and forearm. The measurement stand has been shown in Fig. 1. The strain gauges were fixed, in a plain bridge system, on the arms of the indication bridle transducer fixed to the load.

The signal from the strain gauge was sent to specialized conditioner MC 203 made by Mescomp. The tension signal, proportional to the load force on the handle developed by the operator was, obtained as the conditioner output. Simultaneously, the measured value was monitored (controlled) by the operator on the analog indicator allowing to keep constant load force exerted by the operator on the handle. The motion of the hand-handle system was recorded by high-speed camera Pulnix TM6710 (350 frames/second) and stored in computer’s memory of the analyser Motion Blitz 350. Paths of excitation and measurement are presented in Fig. 2. Registration was done sequentially in the range of frequency 5–85 [Hz] with step 5 [Hz], acceleration of vibrating table 30 [m/s²], feed force of operator’s hand 150 [N]. Similar measurements, concerning the absorbed power by the investigating system, were done and depicted in [1].

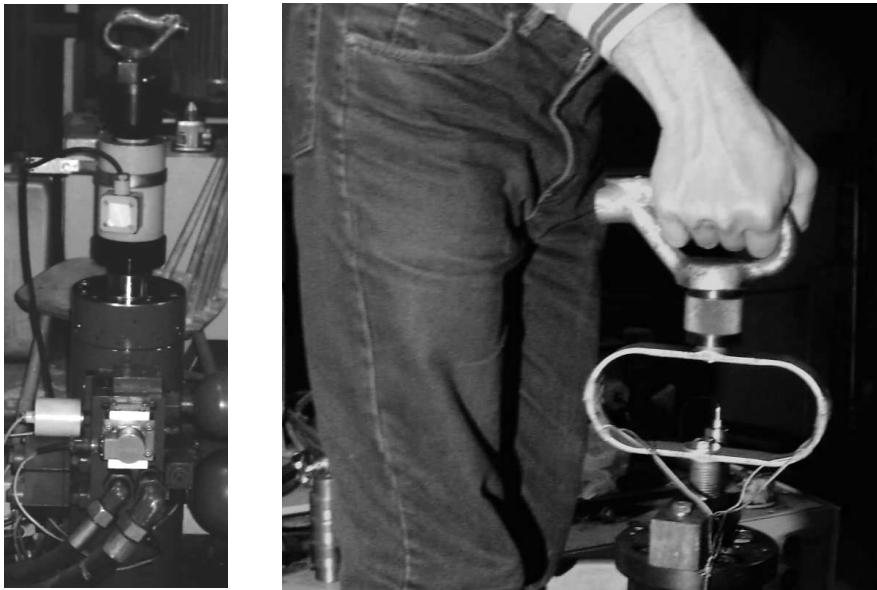


Fig. 1. View of measurement stand.

The applied method of measurement allows to calculate the driving point mechanical impedance. It is based on the analysis of registered films of time histories of velocities of chosen points and load dynamical forces between the handle and shaker table, simulating tool's vibration motion. The optical measurements of force and velocity allow to eliminate the errors concerning the phase angle between F and V caused by application of classical measurement paths.

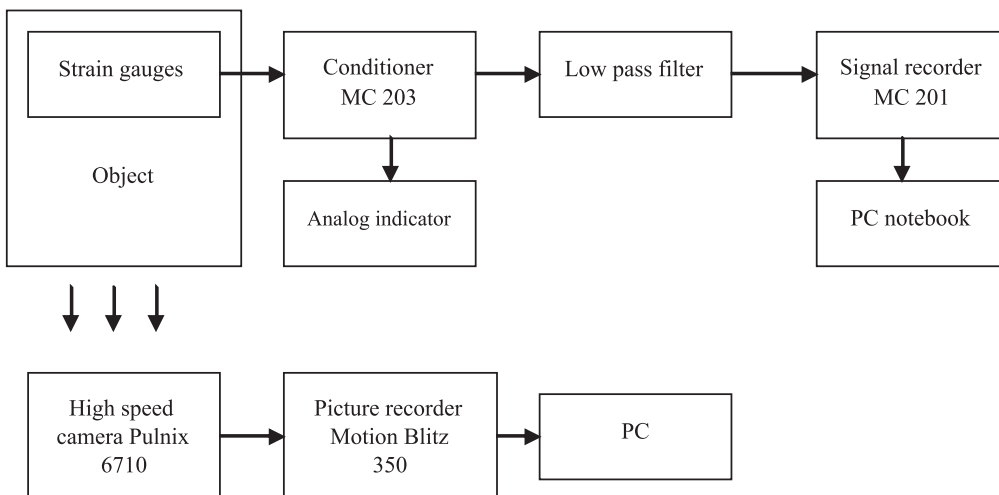


Fig. 2. Scheme of instrumentation and measurement system.

3. Analysis of measurement results

The recorded pictures were numerically analysed. The chosen points of the pictures were marked and their motion was tracked. From the numerical analysis of the values of displacements of these points the time histories of velocities were calculated. The analysis of values of the relative displacements of arms of the load indication bridle allowed to calculate the dynamical force in terms of time. The results of numerical analysis were stored in the matrix form in computer's memory. The specialized WINalyze software and application of subpixel accuracy for motion tracking were used. An exemplary window of motion analysis with marked measurement points is shown in Fig. 3. Figure 4 shows the examples of time histories of the analysed velocities and dynamical forces measured optically and by the strain gauges. In that figure are shown the differences between the relative phases of the considered signals.

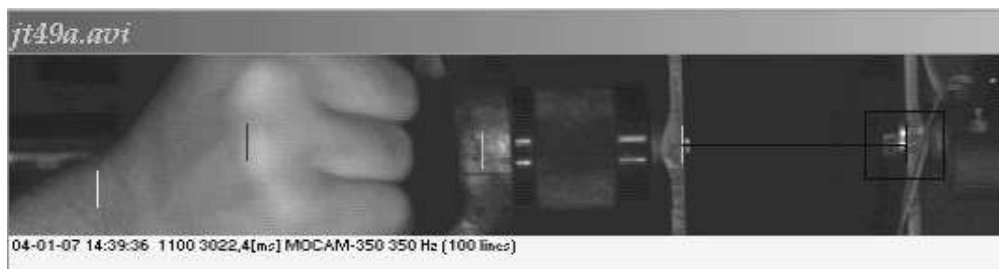


Fig. 3. A picture of hand-handle system with marked measurement points.

Similar time histories of the considered values were obtained for other frequencies of excitations from the range 5–90 [Hz]. The frequency range limitation was forced by internal resonance frequencies of the load indication bridle. From the obtained numerical results, the mechanical impedance in the direction x_h (according to ISO-5349) of the hand-arm system was estimated according to the procedure presented below.

The formula (3) can be rewritten as:

$$Z(j\omega) = \frac{F(j\omega)}{\dot{X}(j\omega)}, \quad (4)$$

where $\omega = 2\pi f$ – angular frequency excitation, $Z(j\omega)$ – complex impedance, $F(j\omega)$ – applied force, $\dot{X}(j\omega)$ – velocity of contact point between handle and hand in the direction of excitation.

Expression (4) can be presented in the form:

$$Z(j\omega) = \frac{F(j\omega)\dot{X}^*(j\omega)}{\dot{X}(j\omega)\dot{X}^*(j\omega)}. \quad (5)$$

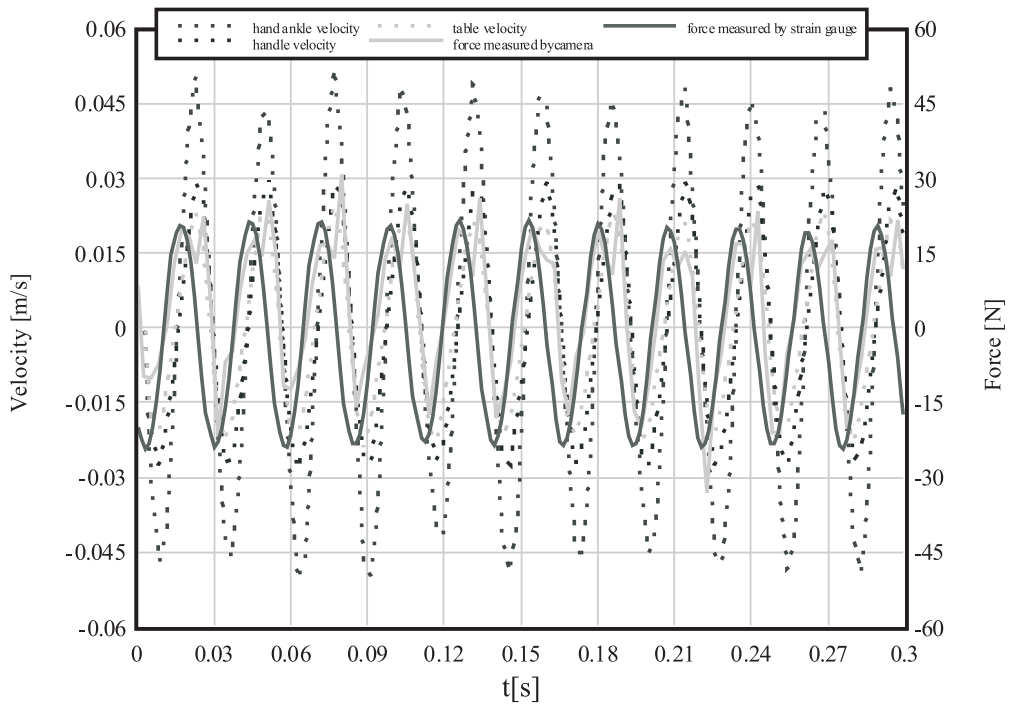


Fig. 4. Time histories of the analysed velocities and dynamical forces.

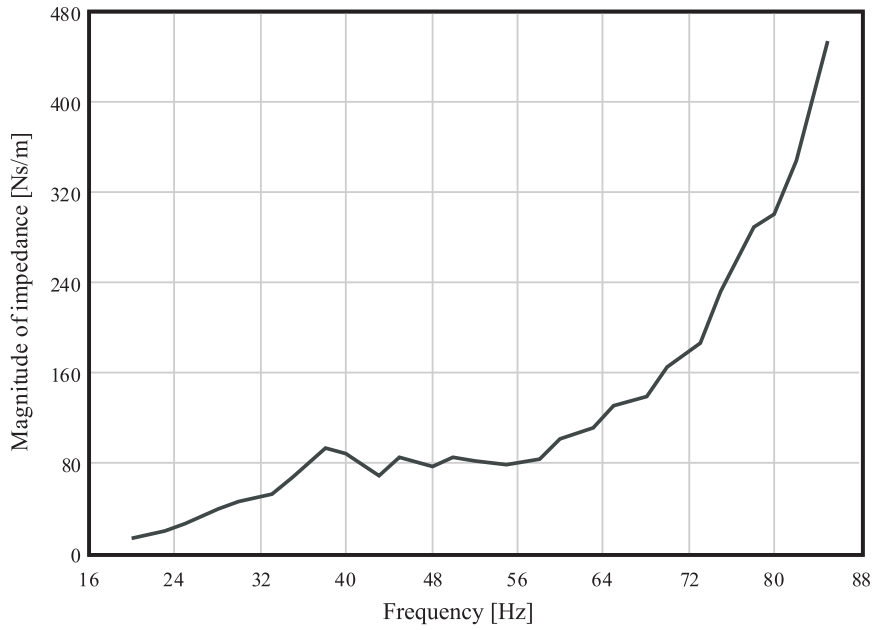


Fig. 5. Magnitude of the mechanical impedance.

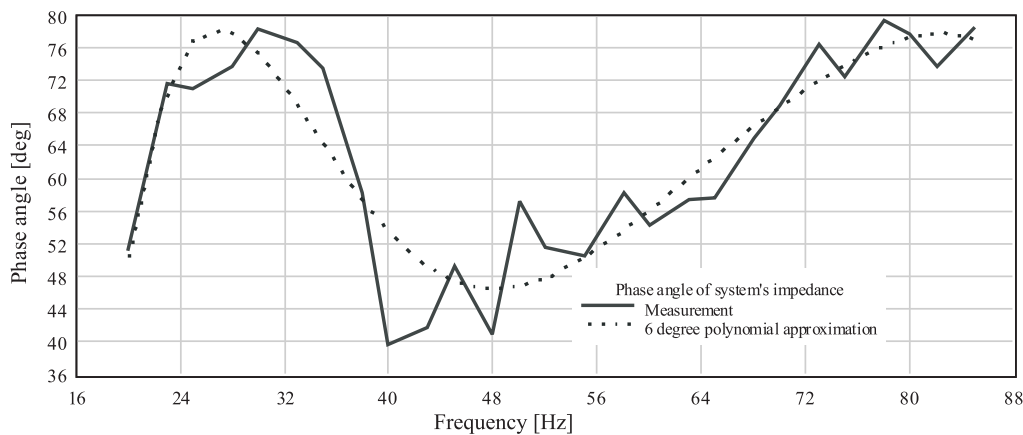


Fig. 6. Phase angle of the mechanical impedance.

Applying the averaging operation on sets of realizations, the formula (5) can be expressed in the form:

$$Z(j\omega) = \frac{P_{\dot{x}F}(j\omega)}{P_{\dot{x}\dot{x}}(j\omega)}, \quad (6)$$

where $P_{\dot{x}F}$ denotes the mutual power spectral density of the signals \dot{x} and F , and $P_{\dot{x}\dot{x}}$ denotes the power spectral density of the signal \dot{x} .

The formulae (5) and (6) were used for calculation of the impedance magnitudes and phases of the investigated system for the assumed range of frequency excitation. The calculations were numerically done by means of the Matlab – Signal Processing software. The numerical values of the magnitude and phase angle of the considered system are shown in Figs. 5 and 6.

4. Comparison of force values obtained from the strain-gauges and numerical analysis of picture

The comparison of the forces obtained from measurement of the displacements and numerical analysis of the picture and the forces obtained from the load indication bridge was done. The registration of the tension variation in the Wheatstone bridge branch coming from the strain gauges and registration of the motion pictures of the considered system were started at the same time by one external signal. The simultaneously registered tension signal and the sequence of pictures were numerically analyzed. Some results of the signal of tension and the sequence of pictures analysis were together presented in the form of plots shown in Figs. 7 and 8 for two different values of frequency excitation.

The results concerning the signal amplitudes, shape and frequencies obtained by two applied methods are, in principle, very similar. However, the significant differences can be observed between the measured phases. The signal coming from the strain gauge, transformed by the electronic amplifier, is delayed in comparison with the real signal

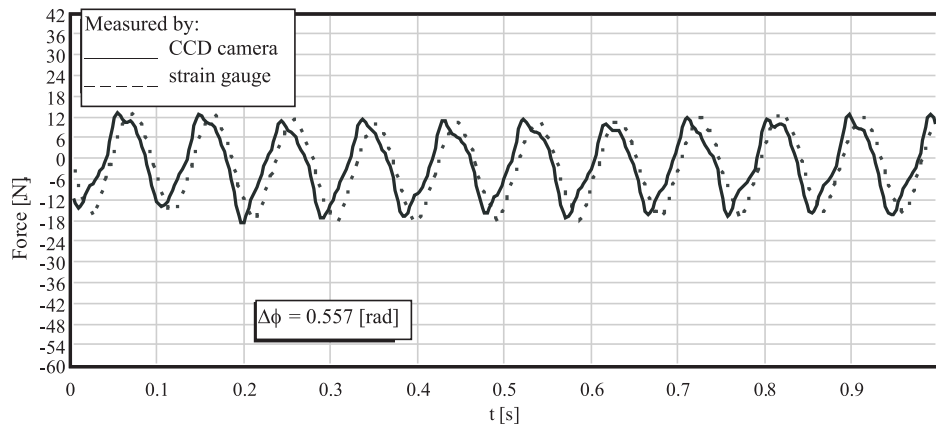


Fig. 7. Comparison of dynamic forces for harmonic excitation 10 [Hz].

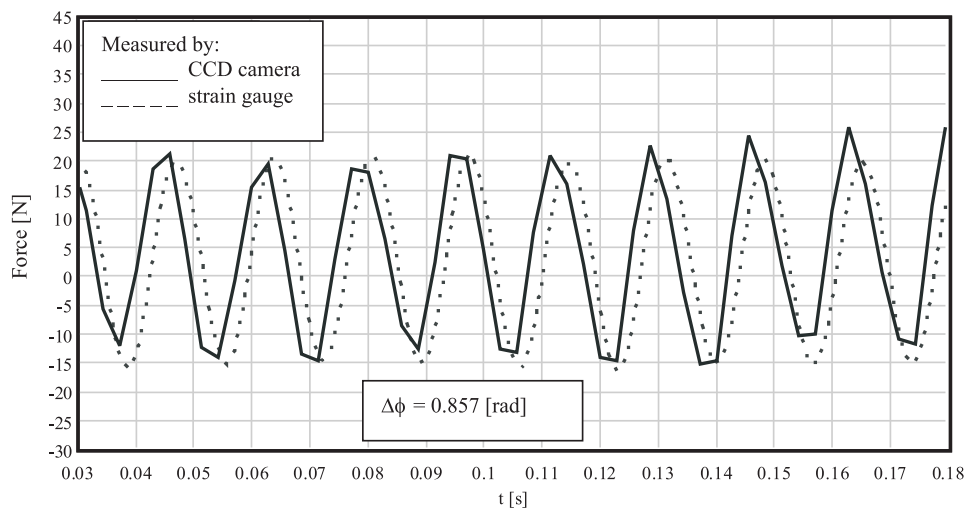


Fig. 8. Comparison of dynamic forces for harmonic excitation 60 [Hz].

measured by the optical method. This delay, as it was shown in Figs. 7 and 8, depends on the frequency of the measured dynamic force and causes errors in all measurements, while the final results depend on phase shift and in particular, on mechanical impedance measurements.

5. Comparison of the obtained results with the results obtained by other authors

The results of the experimental investigations of the hand – arm systems were published by many authors, e.g. [2, 4, 5]. All of them, however, were done by means of the classical methods of measurement basing on impedance heads, accelerometers and piezoelectric sensors of force. The results obtained by the authors of the present paper and some of the results obtained by the other authors, are shown together in Fig. 9 for

the frequency range 0–100 [Hz]. Figure 9 shows the comparison of the magnitudes and angle phases of the mechanical impedance of the hand-arm systems measured in x_h direction (according to ISO 5349).

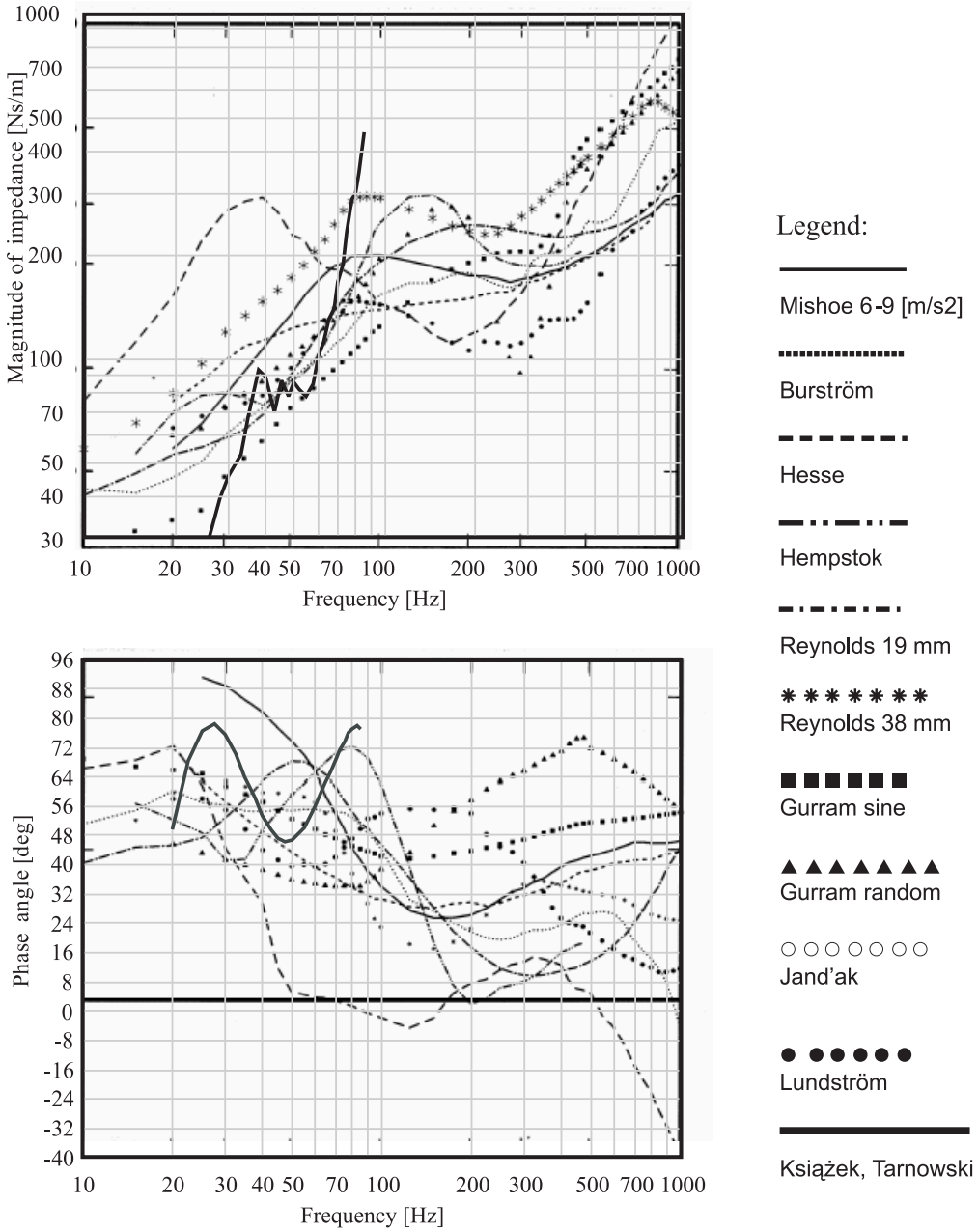


Fig. 9. Comparison of impedances obtained by different authors (results obtained by authors).

6. Conclusions

Basing on the obtained results, the following conclusions can be presented:

- The method based on high-speed camera and specialized software of computer analysis of motion can be applied to measurement of mechanical impedance of the hand-arm system.
- The values of the magnitude and phase angle of the hand-arm system impedance depend very strongly on the conditions of measurement. There are considerable differences between the results obtained by different authors.
- Some common tendencies and similarities in the results shown in Fig. 7 can be observed. One of them is the increase of the value of the impedance magnitude up to the frequency range 100–150 [Hz].
- Local extremum of the of the impedance magnitude in the range 30–40 [Hz] can be observed in authors', Burström's and Reynolds' results.
- The values of the impedance phase angle are comparable for the same range of frequency.

In the paper, the measurements concerning the hand-arm system mechanical impedance were limited to 90 [Hz] because of lack of suitable source of vibration. Comparison of the results of the cited authors shows that the influence of measurement conditions on the final results is essential. One of the reasons of such large differences is the method of measurement of the impedance phase angle. The new way of phase angle measurement allowing for its better estimation has been shown in the present paper.

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