MECHANICS AND CONTROL
Vol. 29 No. 1 2010

Zygmunt BASISTA*, Marek A. KSIĄŻEK*, Janusz TARNOWSKI*

INVESTIGATIONS OF INFLUENCE OF VIBRATION ON HUMAN-OPERATOR CONTROL FUNCTIONS**

SUMMARY

In the paper results of experimental investigations of the system operator-handle-base have been presented. The aim of investigations was to record and analyse dynamical reactions of human operator volunteers participating in the experiments on a visual, suddenly appearing step signal. The main task of each operator was tracking of the signal as precisely as possible with a push force exerted on the tool handle. The measurements were done on an especially designed stand. The stand allows to simulate vibration of the tool with chosen frequencies with or without handle isolation. Time histories of step reference and forces realized by the operator were statistically elaborated and graphically presented.

Keywords: *human-operator, manual control, vibration isolation, percussive tools*

BADANIA WPŁYWU WIBRACJI NA FUNKCJE STERUJĄCE CZŁOWIEKA OPERATORA

Artykuł prezentuje wyniki badań eksperymentalnych układu człowiek operator–narzędzie ręczne. Celem badań była rejestracja i analiza reakcji dynamicznych wolontariuszy biorących udział w eksperymencie na nagły skok sygnału odbieranego zmysłem wzroku. Głównym zadaniem każdego operatora było możliwe dokładne nadążanie za tym sygnałem przez nacisk na rękojeść narzędzia. Pomiary były wykonywane na specjalnie skonstruowanym stanowisku umożliwiającym symulację wibracji narzędzia z wybranymi częstotliwościami, z wibroizolacją rękojeści lub bez wibroizolacji. Przebiegi czasowe sił referencyjnej i zrealizowanej przez operatora zostały poddane analizie statystycznej i zaprezentowane graficznie.

Słowa kluczowe: *układ człowiek operator–narzędzie ręczne, wibroizolacja narzędzia*

1. INTRODUCTION

Design of vibration isolation systems of hand-held percussive tools must be based on modeling of human-operator – tool system. As was proved in (Basista 2001, 2002, 2004, 2005, 2006; Basista and Książek 2004, 2007) suitable modeling of human-operator allows formulation of comfort criteria of work with hand percussive tool. However, the criterion can have more general character than the criterion which concerns only the low level of vibration transmitted through hands to human-operator body. Such possibilities gives the human model which contains not only passive, nonvolitional force of hand arm system (HAS) but describes also volitional force which is transmitted to the tool's handle. The passive forces of pressure on the hand-tool handles are described by the biomechanical models of HAS presented in (Rakheja and Wu 2002).

The volitional acting, changing in time force pressure exerted by the operator on the handle, can be considered as a manual control function in the man-machine system (McRuer and Jex 1967; Sheridan and Ferrell 1974). Percussive tool works with given frequency in cycling way. One can assume that efficiency of work process (velocity of penetration of the tool into base) is proportional to mean in one cycle force exerted on the tool body (Babitsky 1998). This force is the pressure of the operator applied directly to the tool or force transmitted to the tool through the vibration isolation system (VIS). The control process can be schematically presented in Figure 1. A man–operator acts as a regulator in compensatory system trying in the shortest time possible to minimize the difference between the given force P_z and transmitted force P_r called further the realized force. The force P_h is the control force exerted by the operator on the tool handle. Visual feedback is realized as follows: the control force is estimated and applied by operator on the base of observed results of tool work (efficiency) and their comparison with intended aim.

In real conditions of work with hand held tools handle vibration are present almost always. Taking it into account one can demand what is influence of the vibration on the quality of the realized control process.

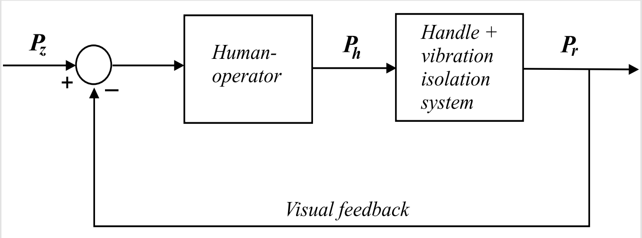

Fig. 1. Scheme of control in human operator-tool system

* Institute of Applied Mechanics, Cracow University of Technology, Krakow, Poland; zbas@mech.pk.edu.pl, ksiazek@mech.pk.edu.pl, jantarno@mech.pk.edu.pl
** This paper is supported by Polish Scientific Committee: PB 1255/T02/2007/32

2. AIM OF INVESTIGATIONS

There were two principal aims of the investigations presented in the paper. The first of them was to estimate degree and way of influence of handle vibration on human-operator behavior concerning control process during work with hand-held tool. The second aim was to estimate influence of VIS, that means the elastic junction of handle and tool body, on the quality of control process. In the experiments the role of the tool was imitated by the mechanical shaker executing harmonic vibration with chosen displacement amplitude and frequency. The obtained dynamical characteristics supplied the data which will allow more precise design of human operator model working in the arduous, heavy conditions. They will also broaden our knowledge concerning criteria of design of vibration isolation of hand held tools. The presented investigations are the continuation of earlier investigations described in (Basista *et al*. 2008, 2009).

3. DESCRIPTION OF STAND AND PROCESS OF MEASUREMENTS

The investigation stand was presented in the real form in Figure 2 and schematically in Figure 3. The participant of the experiments, human-operator, stands on the metal platform which can move very smoothly on the horizontal surface thanks to ball bearings, and applies horizontal pressure force on the handle. One side of the platform was joined to the metal frame by ball-joint and strain-gauge force sensor. The frame was fixed to basis. Such junction allowed measurement of horizontal reaction exerted by operator's legs on the platform. Human operator, in standing position typical for the operators working with of big hand drills, kept handle with right hand and by left hand supported trunk of the tool's model.

The tool model is fixed to the vertical frame throughout the ball joint (articulation) and strain-gauge sensor of force exerted by operator on the tool. On the handle the sensors of acceleration and displacements are fixed. Model's trunk allows for two ways of work:

1) with rigid junction between handle of mass 2.3 kg and working part of the tool,
2) with elastic junction between handle and working part of the tool.

The second way was realized by the application of replaceable springs with coefficient of rigidity 2×10^3 N/m. The stand is composed of immobile and mobile parts. The immobile part is fixed to the basis. One side of the mobile part is joined with the hand tool model by force sensor. The pressure force exerted by the operator is developed on the base of a visual feedback being result of observation of the two monitor indicators showing simultaneously, in real time, given and realized forces. The way of acting of the operator simulates process of control of tool work in the real conditions.

System of data acquisition contains National Instruments measurement card DaQCard 6024E and is controlled by software LabView 7.1. The system generates and records given, reference step function signal. The system records simultaneously signals from two described above strain gauges of force, accelerometer fixed on the tool handle and laser gauge which measures deformation of spring installed between handle and working part of the tool.

Fig. 2. View of stand with human operator

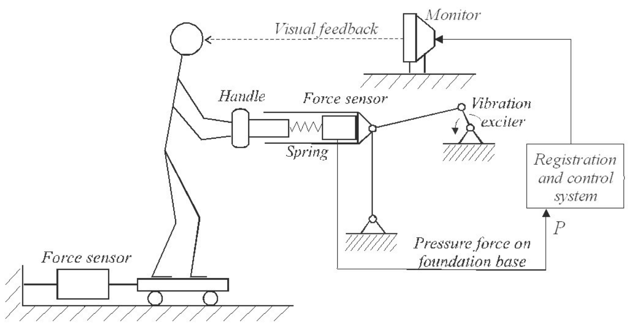

Fig. 3. Scheme of investigation stand

Both strain gauges realized in the full bridge system are plugged to the acquisition data system by dedicated strain amplifiers. The accelerometer and laser gauge are joined correspondingly through dedicated, made in Germany amplifier and dedicated signal conditioner made by RFT µEpsilon. Scheme of investigation and measurement-control system is shown in Figure 3.

The aim of experiences was to record responses (pressure forces on handle) of investigated persons on sudden step signal equals 80 N. The human-operator acted in compensatory system and tried, as was stated above, to minimize in the shortest time possible the differences between the given and realized forces observed on the monitor screen (Fig. 4). Block diagram of instrumentation is shown in Figure 5.

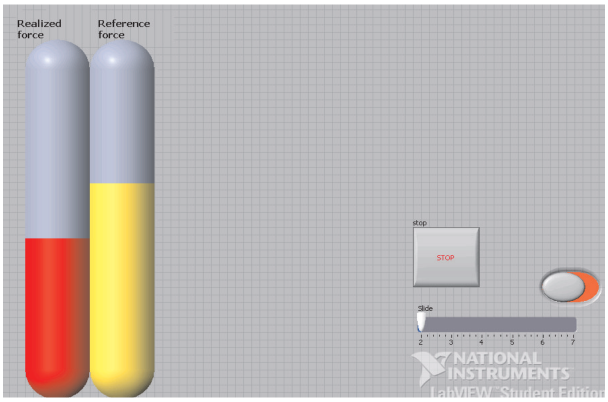

Fig. 4. Operator's control window. Front panel of virtual instrument in LabView 7.1

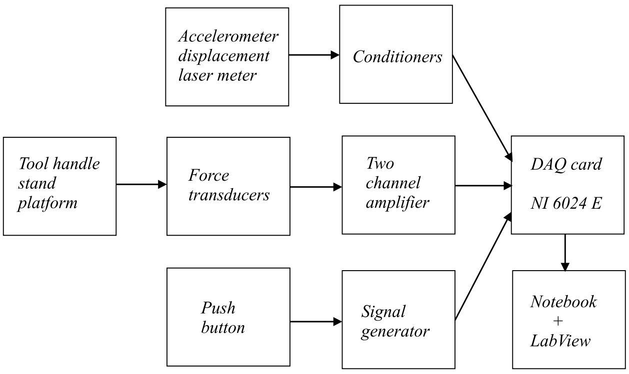

Fig. 5. Block diagram of instrumentation

Group of five participants was investigated. The sinusoidal excitations with 2 mm steady amplitude and sequence of frequencies 5, 10, 15 Hz were transmitted from mechanical shaker to the tool. The human-operators reactions subjected to harmonic excitations on given step signal were recorded for the participants in the following sequence of trails:

1. 3 attempts with immobile basis and firm connection between basis and handle,
2. 3 attempts with immobile basis and elastic connection between basis and handle,
3. 3 attempts with basis vibration with frequency 5 Hz and firm connection between basis and handle,
4. 3 attempts with basis vibration with frequency 5 Hz and elastic connection between basis and handle,
5. 3 attempts with basis vibration with frequency 10 Hz and firm connection between basis and handle,
6. 3 attempts with basis vibration with frequency 10 Hz and elastic connection between basis and handle,
7. 3 attempts with basis vibration with frequency 15 Hz and firm connection between basis and handle,
8. 3 attempts with basis vibration with frequency 15 Hz and elastic connection between basis and handle.

All measurements signals were recorded on hard disc for each of attempts. The recorded signals were numerically analyzed by D-Plot software. Time histories of all the measured signals have been plotted. Exemplary time diagrams, chosen from the set of analyzed signals are shown in Figures 6 – 8.

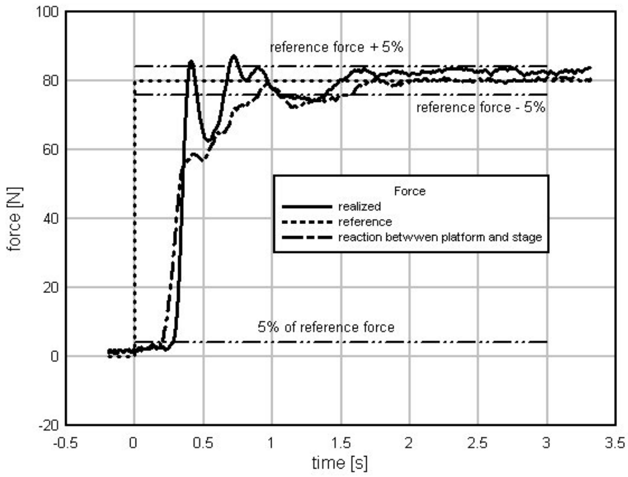

Fig. 6. Example of attempt without excitation and spring

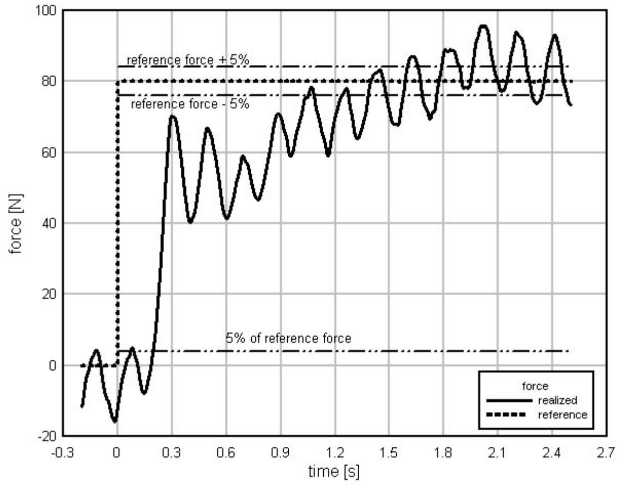

Fig. 7. Example of attempt with excitation 5 Hz

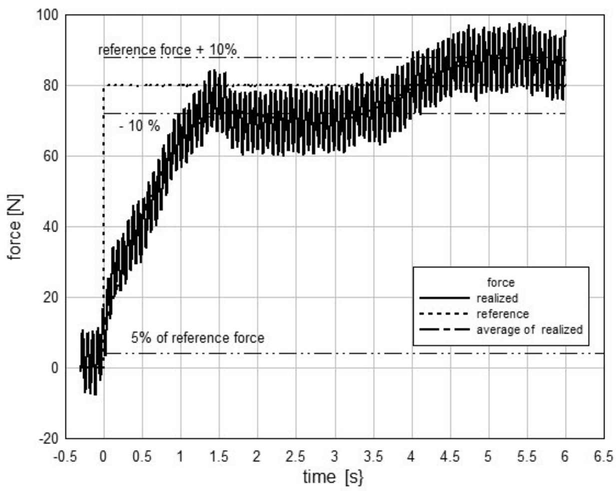

Fig. 8. Example of attempt with excitation 15 Hz

4. RESULTS OF INVESTIGATIONS

The following parameters were calculated and assessed for all of the attempts: rise time, regulation time, overshoot and settling time. The exemplary time history is shown in Figure 9.

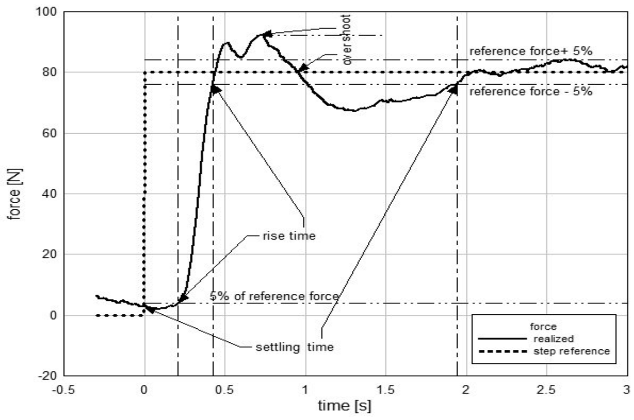

Fig. 9. Exemplary time history
with marked analysed values

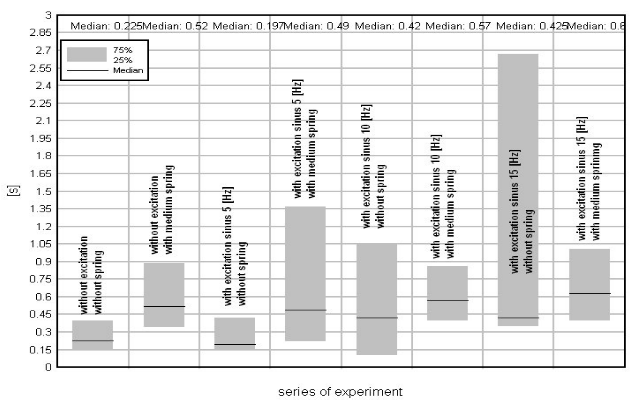

Fig. 10. Rise time in series of experiments
with different excitation

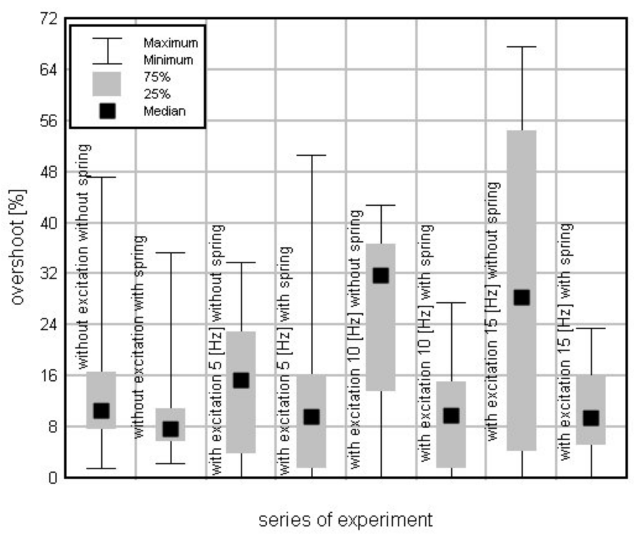

Fig. 11. Overshoot in series of experiments
with different excitation

For the most attempts with vibrated basis, bandwidth ±5% of value reference signal, was not attainable. In all such cases instead of the settling time the possible narrowest bandwidths have been calculated, in which the realized control signals can be included. The results of the analysis and calculations are shown as diagrams in Figures 10, 11 and 12.

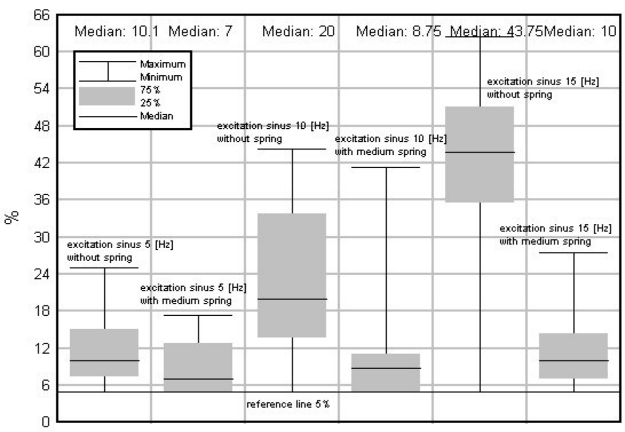

Fig. 12. Possible control bandwidth in % of value
of reference force

5. CONCLUSIONS

- Tool's vibration has big influence on control process and pressure force exerted by operator on handle's tool.
- All fundamental indices of estimation of control process deteriorate with increasing of vibration frequency.
- Vibration frequency increase causes important values distribution of results of measurements.
- Application of vibration isolation system makes rise time of reaction longer in both cases with and without the vibration excitation.
- Overshoot increases with frequency increase for the tool without VIS. For the tool with VIS overshoot almost does not depend on frequency.
- Tool's vibration makes impossible to keep the pressure control force in the bandwidth ±5%.
- Ranges of bandwidth of quasi constant control forces during the vibration depend on frequency of vibration and the rigidity of vibration isolation system (VIS).
- Range of bandwidth in which keeping of control signal becomes possible depends on frequency of tool vibration. For the tools without VIS the range of bandwidth increases stronger with frequency increase. For the tools with VIS the range of bandwidth increase is moderate.

References

Basista Z. 2001, *Modelowanie i symulacja układu człowiek-narzędzie-podłoże*. Zeszyty Naukowe Politechniki Krakowskiej Mechanika, nr 83, pp. 21–30.

Babitsky V.I. 1998, *Hand-held percussion machine as discrete non-linear converter*. Journal of Sound and Vibration, 214(1), pp. 165–182.

Basista Z. 2002, *Wpływ aktywnej wibroizolacji rękojeści na ergonomiczny komfort operowania ręcznym narzędziem udarowym*. Zeszyty Naukowe Politechniki Rzeszowskiej, nr 197, Mechanika, z. 60, pp. 19–26.

Basista Z. 2004, *Modelowanie i badania symulacyjne układu: człowiek-narzędzie ręczne.* PTSK, Symulacja w badaniach i rozwoju, Kraków, ISBN 83-7242-3180, pp. 27–34.

Basista Z. 2005, *Symulacja eksperymentu dla zbadania wpływu układu wibroizolacji na jakość operowania ręcznym narzędziem udarowym.* Folia Scientinarium Universitatis Technical Resoviensis, Nr 222, Rzeszów, ISSN 0209-2689, pp. 11–18.

Basista Z. 2006, *Simulation investigation of an active vibration protection system of an operator of a hand-held percussive tool*. Engineering Transactions, 54, 3, pp. 173–187.

Basista Z., Książek M. 2007, *Criteria of estimation of active vibration isolation system in hand-held percussive tools.* Mechanics, AGH University of Science and Technology, vol. 26, No. 4, ISSN 1734-8927, pp. 160–168.

Basista Z., Książek M. 2008, *Estimation of comfort parameters of an active vibration isolation system of handle of percussive power tool.* Proc. "INTER-NOISE'2004" Prague.

Basista Z., Książek M., Tarnowski J. 2008, *Testowe badania doświadczalne reakcji człowieka-operatora narzędzia ręcznego przy sinusoidalnym sygnale wejściowym.* Czasopismo Techniczne, z. 1-M/2008, ISSN 0011-4561, pp. 27–35.

Basista Z., Książek M., Tarnowski J. 2009, *Experimental investigations of human-operator as a pressure force regulator in man-hand tool system.* Archives of Control Sciences, vol. 19(LIV), No. 1/2009, Polish Academy of Sciences, Committee of Automatic Control and Robotics, ISSN 0004-072X.

McRuer D.T., Jex H.R.1967, *A review of quasi-linear pilot models.* IEEE Transactions on Human Factors in Electronics, vol. HFE 8, No. 3, September 1967, pp. 231–249.

Rakheja S., Wu J.Z. 2002, *A comparison of biodynamic models of the human hand-arm system for applications to hand-held power tools.* Journal of Sound and Vibration, 249(1), pp. 55–82.

Sheridan T.B., Ferrell W. 1974, *Man-Machine Systems.* The MIT Press, Cambridge.

Sövényi Sz., Gillespie R.B. 2007, *Cancellation of biodynamic feedthrough in vehicle control tasks.* IEEE Transactions on Control Systems Technology, vol. 15, No. 6, pp. 1018–1028.