Journal of Achievements in Materials and Manufacturing Engineering
VOLUME 38
ISSUE 2
February
2010

# Computer-aided synthesis and analysis of discrete mechanical systems

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Received 20.11.2009; published in revised form 01.02.2010

Analysis and modelling

## ABSTRACT

**Purpose:** The main objective of this study is to present and describe major properties of software that has been developed by the author himself with the purpose to support the synthesis and analysis of vibrating systems. The synthesis is the reverse task as compared to the analysis as it is intended to achieve a system that meets already assumed requirements related to the value of vibration frequency.
**Design/methodology/approach:** The conventional approach to design complex systems is frequently time consuming and provides a guarantee that it leads to satisfying results they can never be taken for granted. Therefore, application of the other, non-conventional methods proved to be necessary, such as combined structural and parametric synthesis. As a final result of that, a method of the desired structure is obtained along with such parameters of individual system components which meet the presumed requirements.
**Findings:** The presented software has one substantial advantage, which is the fact that no mathematical models that are used to describe the system must be defined anew when any of the system parameters or the system structure are altered. The software enables also to compare passive and active suppression of vibrations. The analyses that have been carried out with the use of the software provide a proof that application of active vibration-suppressing components leads to better results than when only passive components are used.
**Research limitations/implications:** Scope of deliberations is limited to discrete mechanical systems that exercise longitudinal vibrations and incorporate either passive or active vibration-suppressing components, but for this type of systems, this approach is sufficient.
**Practical implications:** The methods of reverse task and analysis can be a base of design and construction for this type of mechanic systems.
**Originality/value:** The possibilities and operation of the author's program supporting the synthesis and analysis of discrete mechanical systems are also discussed. By means of this software it is possible to carry out the analysis and synthesis of discrete systems containing both active and passive elements that reduce vibrations.
**Keywords:** Process systems design; Synthesis; Reduction of vibrations

**Reference to this paper should be given in the following way:**
K. Białas, Computer-aided synthesis and analysis of discrete mechanical systems, Journal of Achievements in Materials and Manufacturing Engineering 38/2 (2010) 171-178.

## 1. Introduction

Vibration is the phenomenon that is frequently witnessed in the surrounding environment. Harmful effect of vibrations is associated with their influence on improper operation of machinery and equipment, although adverse impact of vibration on human body is also well known. That is why suppression of undesired vibrations is perceived as a problem of great importance. Therefore, the task of designers and developers of equipment and real facilities to counteract improper use or operations of the machinery, both in case of newly designed equipment and while tuning up the already manufactured and operated machinery to the desired demands [1-7].

There are many ways how to prevent machinery and equipment from excessive vibrations that adversely affect their subassemblies and components. In particular, they include passive, semi-active and active systems intended to suppress vibrations. The characteristic feature of passive systems is their capability only to dissipate the vibration energy or to accumulate it periodically with no possibility to change their parameters over time. Semi-active systems incorporate passive components, but contrary to purely passive systems they may subject to alterations. On the other hand, active systems use external sources of energy to produce vibrations that compensate primary vibrations of the systems [2, 4, 5, 8-10].

The software that is presented herein is subdivided into two subroutines. The first one is dedicated to an analysis and synthesis of cascade systems (*Synthesis of Cascade Mechanical Systems*, in Polish: ***S****ynteza* ***K****askadowych* ***U****kładów* ***M****echanicznych*) while the second one is meant to analyse and synthesise branched structures of mechanical systems (*Synthesis of Branched Mechanical Systems*, in Polish: ***S****ynteza* ***R****ozgałęzionych* ***U****kładów* ***M****echanicznych*).

The synthesis [3-5, 8-12] process that is carried out with the use of the presented software consists in determination of the system structure and its parameters on the basis of initial requirements, such as resonance and antiresonance frequencies of the system.

The analysis [10, 13-15] makes it possible to obtain a series of graphs for amplitudes or deflections of the system that may be furnished with either active or passive components to suppress vibrations. The software enables also to select passive or active measures for vibration damping.

The description how to use the subroutine *Synthesis of Cascade Mechanical Systems* (in Polish: *Synteza Kaskadowych Układów Mechanicznych*) can be presented on an example of the synthesis and analysis processes that are performed for a restrained cascade system with three degrees of freedom. The system is subjected to the effect of dynamic excitations that are applied to the first inertial component. The considered structure comprises suppressing components in the form of viscotic dampers and they are proportional to resilient parts. Active components are embedded in-between inertial modules.

## 2. Description of the software operation SKUM

After having the software started up the display presents the first screen dedicated to selection of parameters, just as shown in Fig. 1.

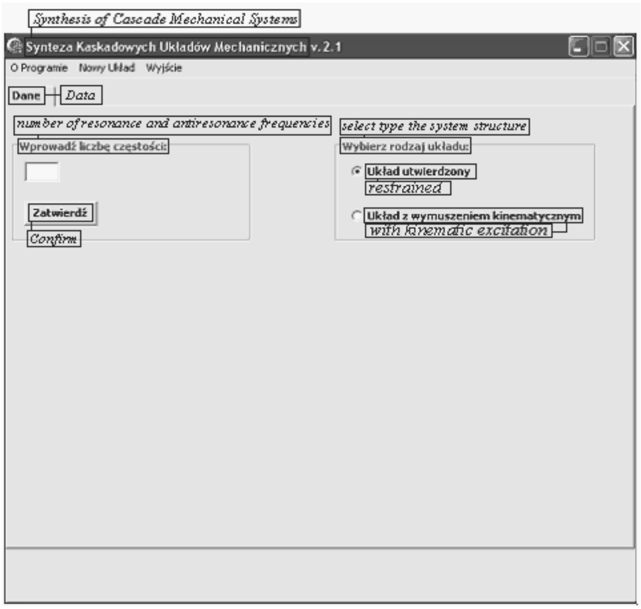


Fig.1. The main program window

The first step that must be taken by the software operator is to select a type of the system structure along with the excitation type (*restrained, with kinematic excitation,* in Polish: *utwierdzony, z wymuszeniem kinematycznym*) and the number of resonance and antiresonance frequencies, all these selections are performed under the menu item *Data (*in Polish: *Dane)* – Fig. 2.

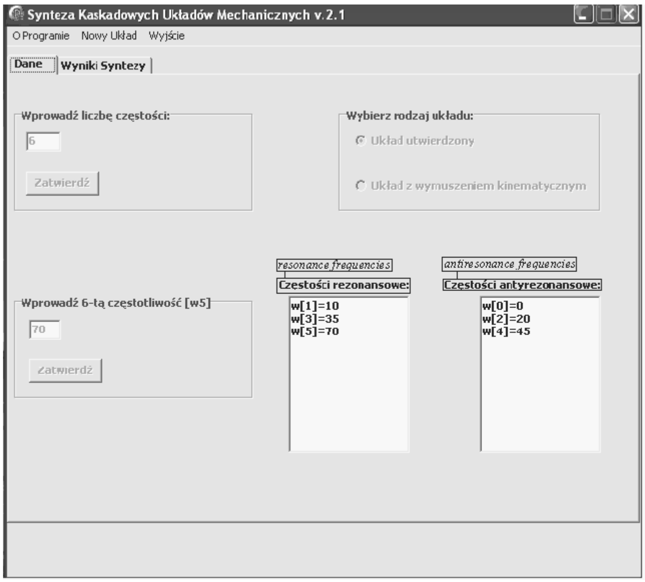


Fig. 2. Introducing frequencies

During the subsequent step one has to use the software submenu *Results of Synthesis (*in Polish: *Wyniki Syntezy)* that brings together values of individual inertial and resilient components as well as the system model (Fig. 3). This window is also used to define a number of dynamic excitations along with their values (Fig. 4).

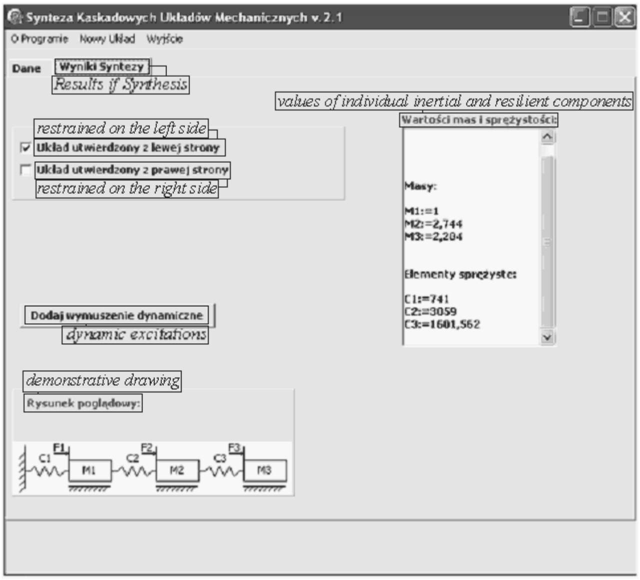


Fig. 3. Results of synthesis

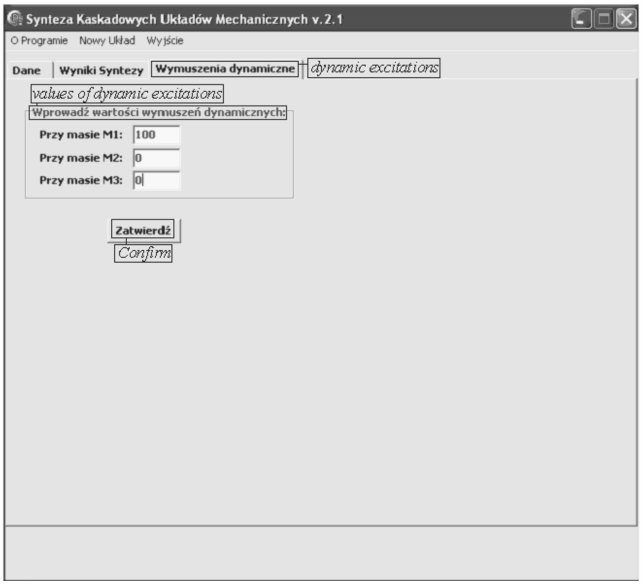


Fig. 4. Dynamic excitations

Upon completion of settings for dynamic excitation they must be acknowledged by depressing the *Acknowledge* button *(*in Polish: *Zatwierdź).* After having the option selected a screen is displayed with diagrams for the system amplitudes (Figs. 5-7). To see the subsequent graphs the operator must move the slider *Amplitude index (*in Polish: *Indeks amplitudy).*

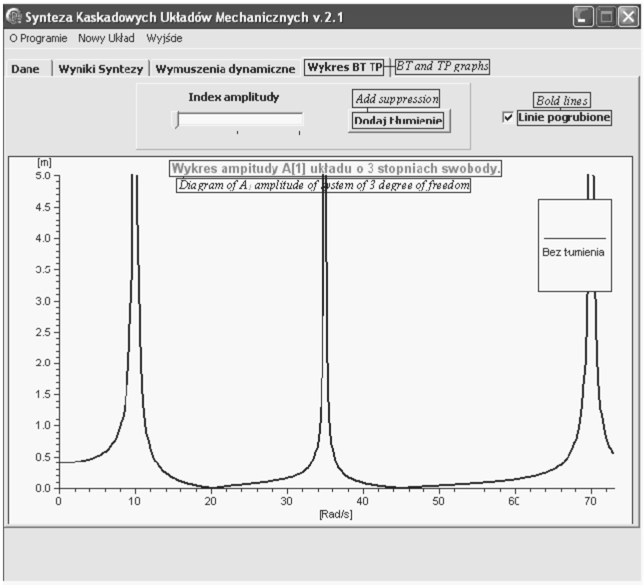


Fig. 5. Diagram of $A_1$ amplitude

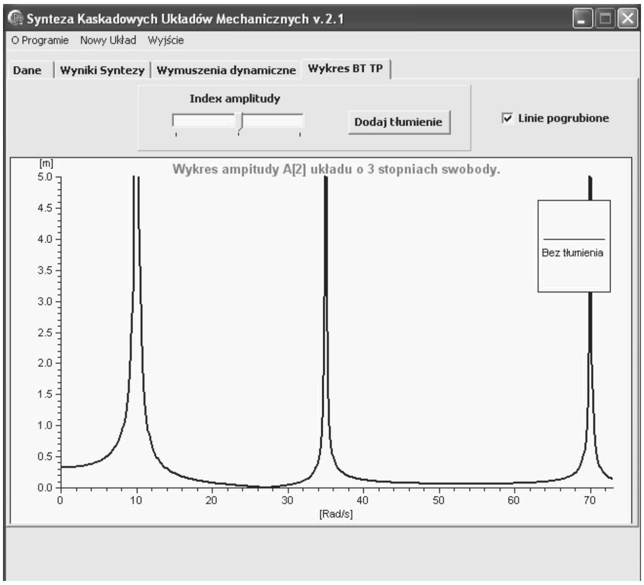


Fig. 6. Diagram of $A_2$ amplitude

Vibrations can be suppressed either by application of passive components (dampers) or active parts that are capable to generate counteracting forces intended to reduce deflections of the system.

Passive and /or active components meant to suppress vibrations can be incorporated into the system with the use of the window *Add suppression (*in Polish: *Dodaj tlumienie).* After having the option activated the screen is displayed where the type of suppression can be selected (Fig. 8). When the passive damping method is used it is necessary to select the proportional coefficient from the specific range of values.

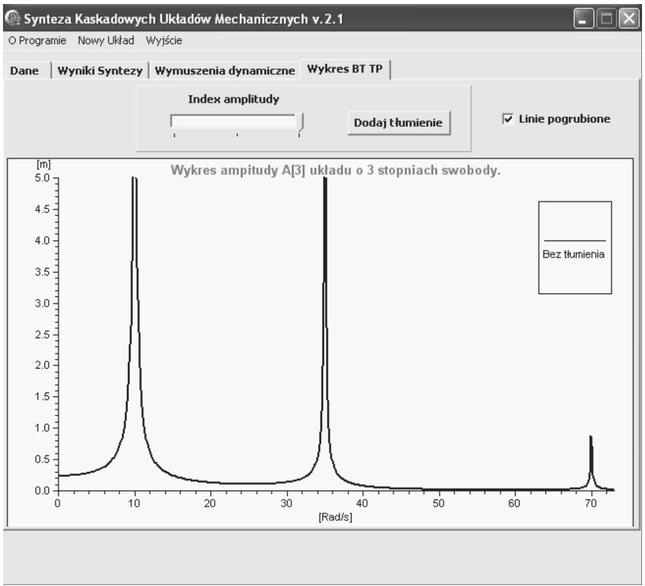


Fig. 7. Diagram of $A_3$ amplitude

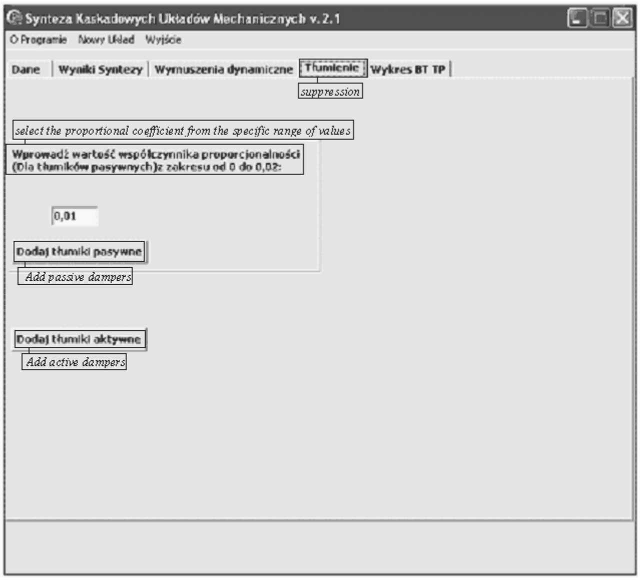


Fig. 8. The window of the damping selection

When the value of the damping coefficient is selected the display shows graphs for the system amplitudes without damping and for deflections with passive damping (*BT and TP graphs* – in Polish: *Wykresy BT TP*). The blue line distinguishes graphs of the function when only passive damping is applied to suppress the system vibrations while the red line appears when no suppression is used (Figs. 9-11).

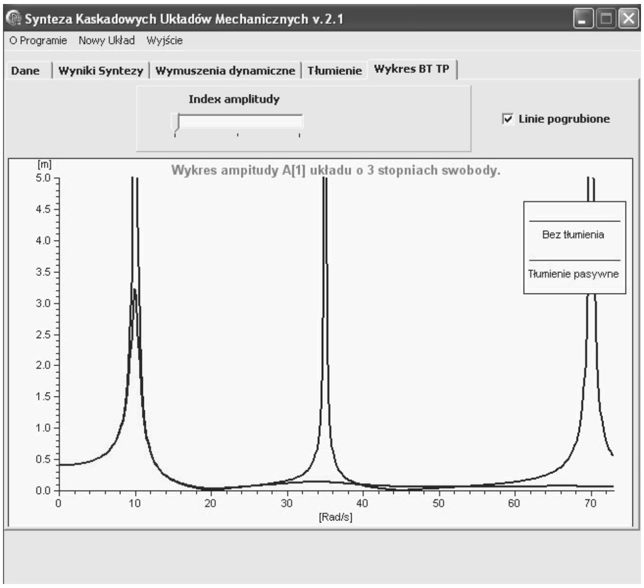


Fig. 9. Diagram of $A_1$ amplitude and maximum displacement

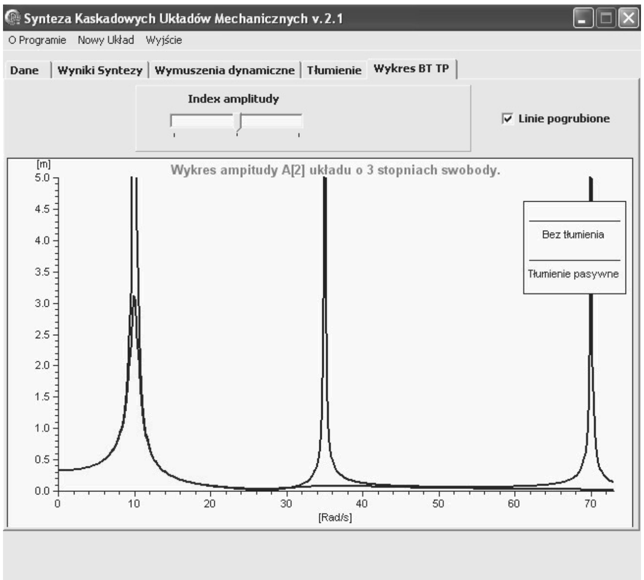


Fig. 10. Diagram of $A_2$ amplitude and maximum displacement

To find out the values for active components intended to mitigate vibrations partially of the analysed system, one has to move back to the tab *Damping (*in Polish: *Tłumienie)* and then select the option *Add active dampers (*in Polish: *Dodaj tłumiki aktywne).* After the function is selected the screen presents a mimic diagram of the system with its active components along with numerical values for individual components corresponding to each specific frequency of the system free vibrations (Fig. 12).

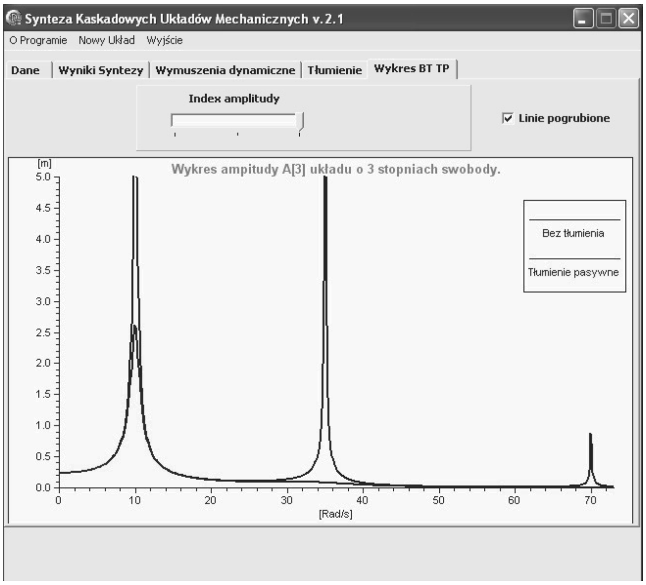


Fig. 11. Diagram of $A_3$ amplitude and maximum displacement

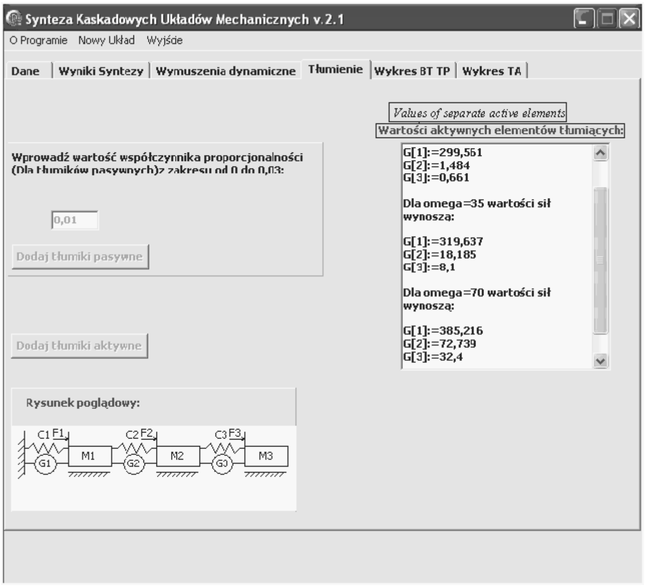


Fig. 12. Values of separate active elements

When calculation of values for active components is completed the operator can select the tab (function menu) *TA Graphs (*in Polish: *Wykresy TA)* and use these graphs to compare deflection of the system that is affected by active components (red lines) as well as graphs for amplitudes of the system when no reductions of vibrations is applied (black lines). Graphs for amplitudes and maximum displacements are presented in Figs. 13-21.

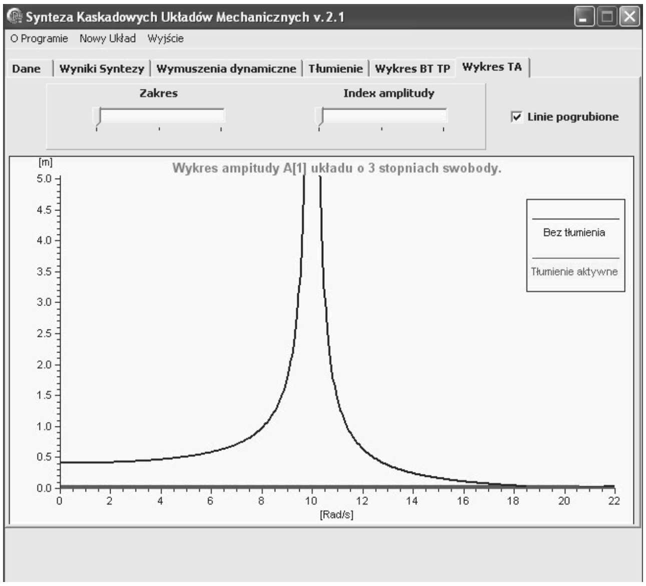


Fig. 13. Diagram of $A_1$ amplitude and maximum displacement of system at $\omega = 10\,\frac{rad}{s}$

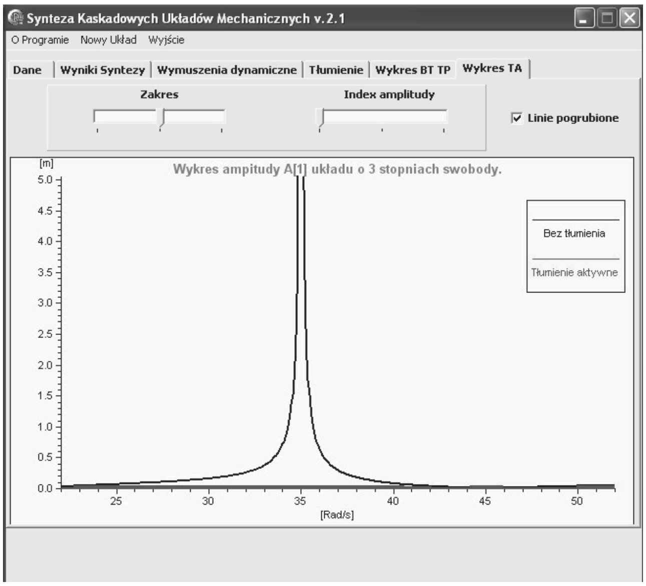


Fig. 14. Diagram of $A_1$ amplitude and maximum displacement of system at $\omega = 35\,\frac{rad}{s}$

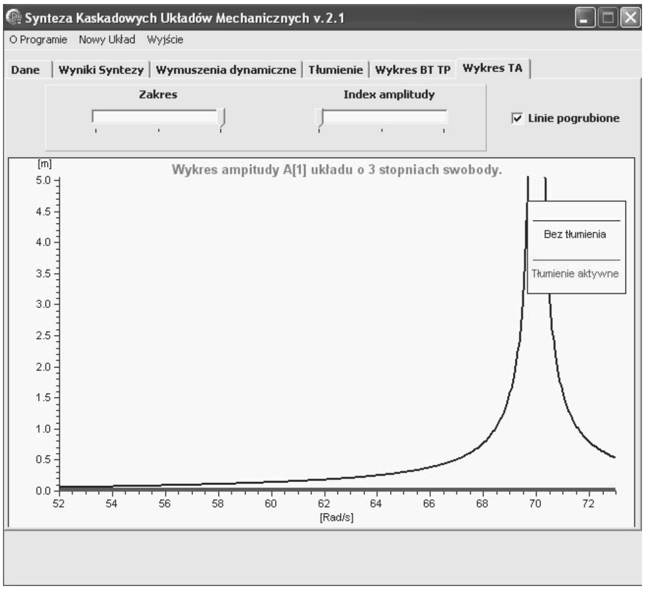


Fig. 15. Diagram of $A_1$ amplitude and maximum displacement of system at $\omega = 70\frac{rad}{s}$

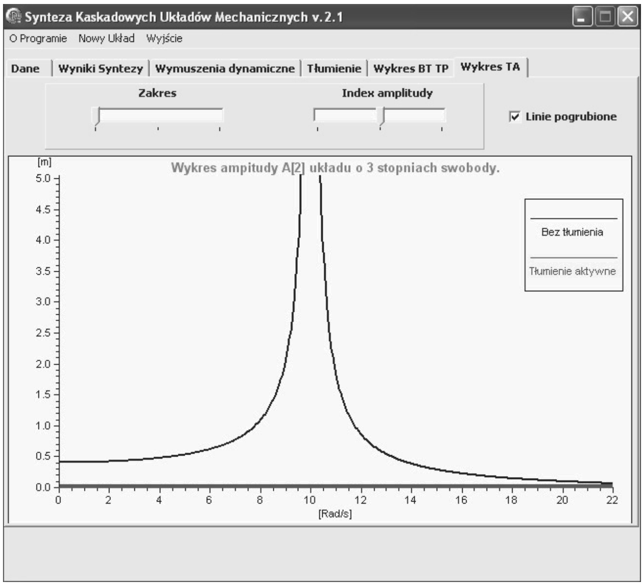


Fig. 16. Diagram of $A_2$ amplitude and maximum displacement of system at $\omega = 10\frac{rad}{s}$

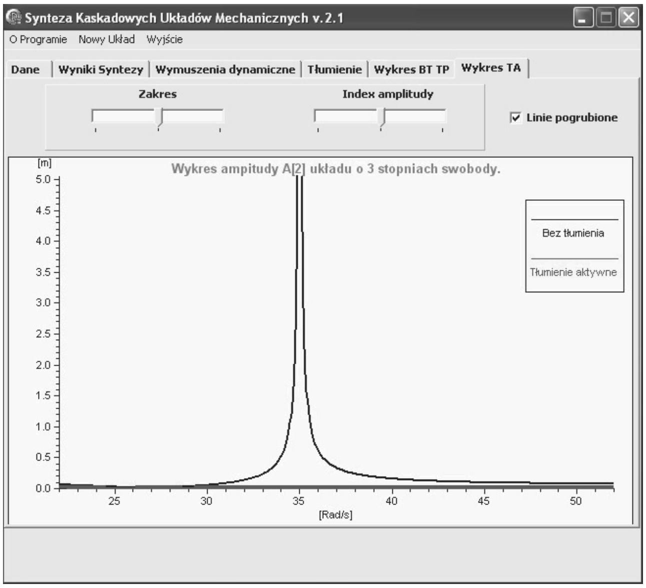


Fig. 17. Diagram of $A_1$ amplitude and maximum displacement of system at $\omega = 35\frac{rad}{s}$

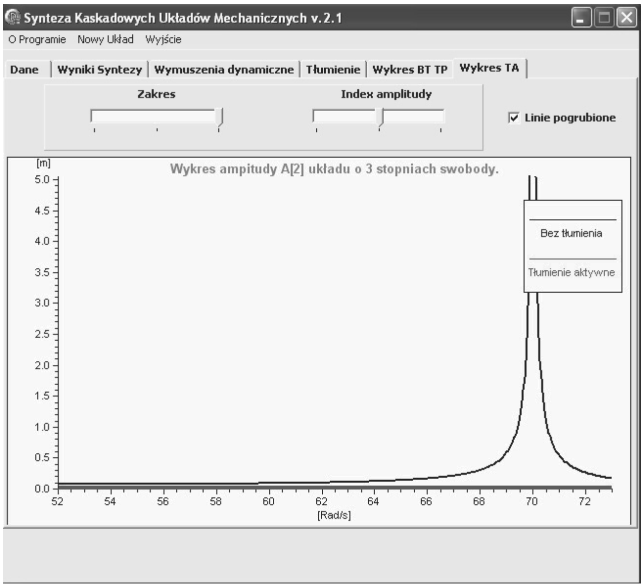


Fig. 18. Diagram of $A_2$ amplitude and maximum displacement of system at $\omega = 70\frac{rad}{s}$

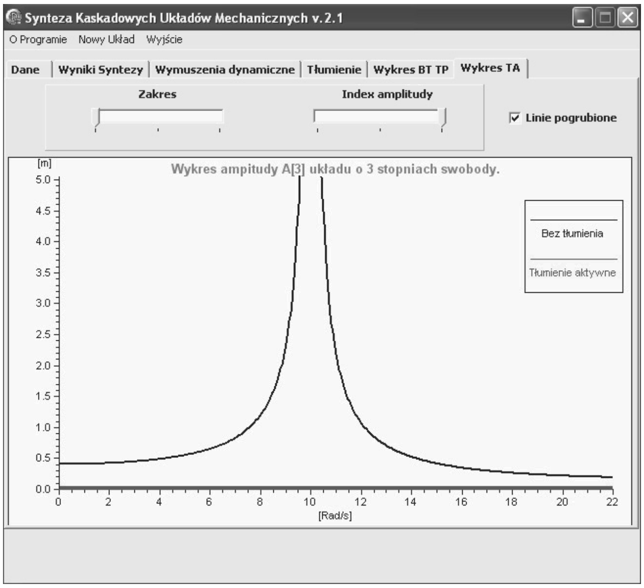


Fig. 19. Diagram of $A_3$ amplitude and maximum displacement of system at $\omega = 10\frac{rad}{s}$

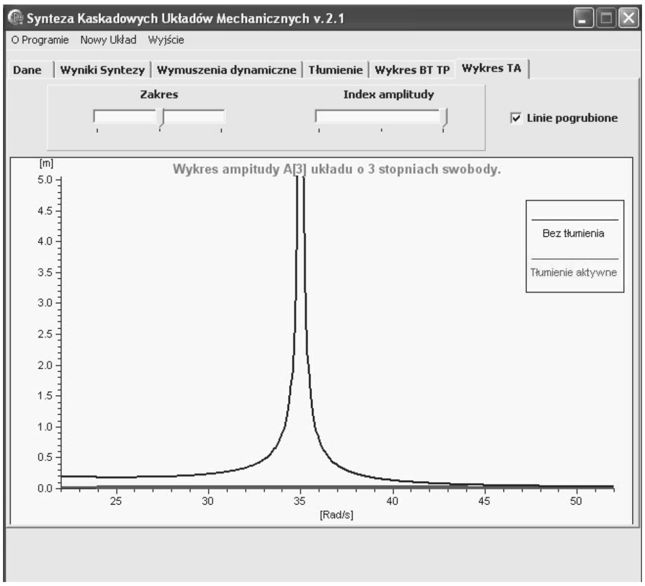


Fig. 20. Diagram of $A_3$ amplitude and maximum displacement of system at $\omega = 35\frac{rad}{s}$

The menu option *Quit (*in Polish: *Wyjście)* is used to stop operation of the software. When the user intends to move to deal with a new system instead of quitting the software, the menu option *New system (*in Polish: *Nowy Układ)* should be selected. Further steps are fully identical as in case of the foregoing example.

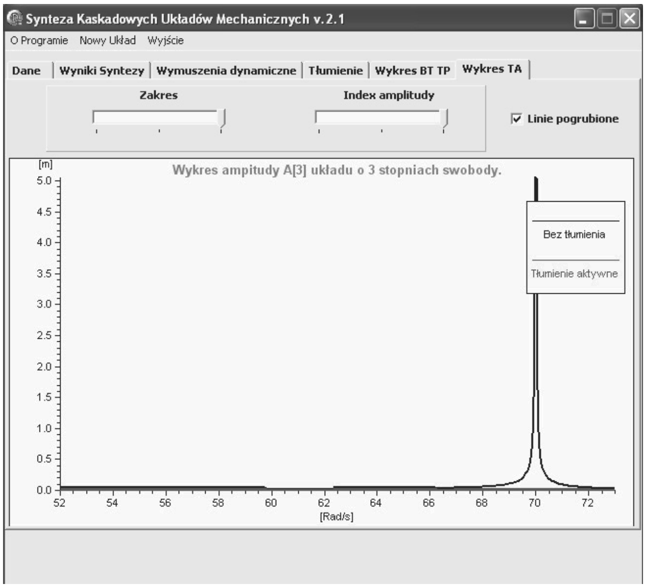


Fig. 21. Diagram of $A_3$ amplitude and maximum displacement of system at $\omega = 70\frac{rad}{s}$

The software enables investigation of the systems that are restrained at one side or at both sides and that are affected by a kinematic excitation.

## 3. Conclusions

The paper presents operation of the one's own-developed software intended for computer-supported synthesis of discrete mechanical systems.

The software makes it possible to compute values of forces that are generated by active components and to find out values of passive components intended to suppress vibrations. In addition, software users are capable to plot amplitude vs. phase characteristic curves of the system with the aim to illustrate effect of both active and passive components embedded within the system.

The newly developed application software substantially cuts down the time necessary to synthesise and analyse vibrating mechanical systems. The substantial advantage of the software is the fact that no mathematical models used to describe the system must be defined anew when any of the system parameters or the system structure are altered.

## Acknowledgements

This work has been conducted as a part of the research project no. N N501 222035 supported by Polish Ministry of Scientific Research and Higher Education in 2008-2010.

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