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RESEARCH ON THE INFLUENCE OF COMPOSITE MATERIALS ON THE INTEGRITY OF THE SUPPORTING STRUCTURE OF THE MACHINE EXPOSED TO VARIABLE STRESS

ISTRAŽIVANJE UTICAJA KOMPOZITNIH MATERIJALA NA INTEGRITET NOSEĆIH STRUKTURA MAŠINA IZLOŽENIH PROMENLJIVOM NAPREZANJU

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Keywords
- composite materials
- amplitude of displacement
- damping coefficient
- vibration
- supporting structure

Abstract

Damping coefficients for different compositions of composite materials are calculated and analysed. The damping coefficient is taken into calculations of dynamic behaviour of the supporting structure, providing new solutions in the construction of the supporting structure of the machines.

Ključne reči
- kompozitni materijali
- amplituda pomeranja
- koeficijent prigušenja
- vibracije
- noseće konstrukcije

Izvod

Koeficijent prigušenja za različite sastave kompozitnog materijala je proračunat i analiziran. Sam koeficijent prigušenja dalje se uzima u proračunima dinamičkog ponašanja nosećih struktura mašina i time dobijaju nova rešenja u konstruisanju nosećih struktura mašina.

INTRODUCTION

By analysing machines for the processing of materials /1/, one can conclude that they consist of a large number of separate parts, different in function, according to different principles of action and different in shape and size.

The basic elements are those parts without which the machine is not able to perform its primary function:
support structure, whose task is to connect all the other elements of the machines in a unique unit and maintain their configuration relationships and movements;
drive system and executive parts;
system for command and control, and
lubrication system.

Considering conditions such as low price, type of available energy, large number of drive solutions and the executing parts of machine, it is the support structure where serious problems occurs, including:
strength, which requires optimal choice of materials, to obtain a lighter structure;
static and dynamic stability, to ensure the precision of work i.e. minimum displacement of tools from ideal position in relation to the work piece;
spatial distribution of non-moving parts, to get optimal functioning, and more aesthetic appearance;
practical performance of support structure, i.e. its assembling and disassembling;
easy access to the workspace, especially for large workspaces;
problem of safety at work.

The most important ways to increase the accuracy of the machine is to decrease negative influence of elastic deformations using closed-supporting structures (portal type machines), additional stiffening and eliminating the console system (or decreasing their length), and increasing the stiffness of the supporting structure by decreasing movable and non-movable connections.

Based on previously listed proposals, but in order to increase the exploitation, greater stiffness, better balance, improved positioning and smaller displacements, the closed type of machine support structure is chosen to be considered here.

The basic form consists of a desk, trim and columns, taking into account that in some cases desk as a separate element does not exist, i.e. that columns are placed on fundamental grounds.

Basic materials used for support structures are steels (plates and profiles), cast steel, cast iron and nodular cast iron, /1/. They all have their advantages and disadvantages in relation to each other, but it can be said that such structures are rather expensive and they have limit in terms of dimensions that can be made.

For the purpose of price cut, as well as the increase in the dimensions, use of the composite materials, like iron-concrete, is considered. Dynamic model of the closed support structure, either single piece or divided, for applying analytical methods for calculation, can be represented as in Fig. 1.

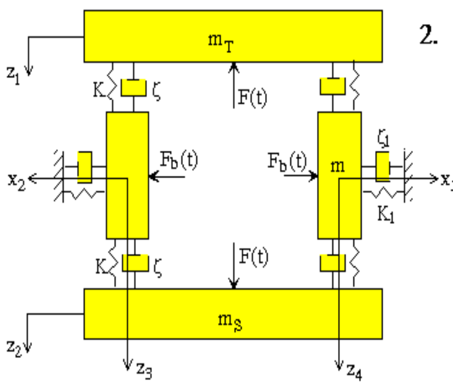

Figure 1. Dynamic model of machine support structure.
Slika 1. Dinamički model noseće strukture mašina

ABSORBING LINING OF COMPOSITE MATERIALS

Many different shapes and constructions, as parts of the support structure, exist nowadays, as well as examples with and without absorbing lining, Fig. 2, /2/.

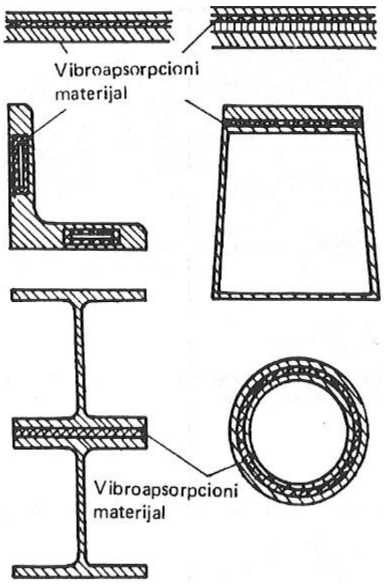

Figure 2. Different forms of machine parts with cladding.
Slika 2. Različiti oblici delova mašina sa oblogama

The panel with sided lining

At the sided (simple) lining, absorption materials are applied on one side of the panel with oscillations that should be reduced, Fig. 3. In Fig. 3a the unloaded panel with sided lining is shown, whereas the process of folding panel and built-absorbent material is shown in Fig. 3b.

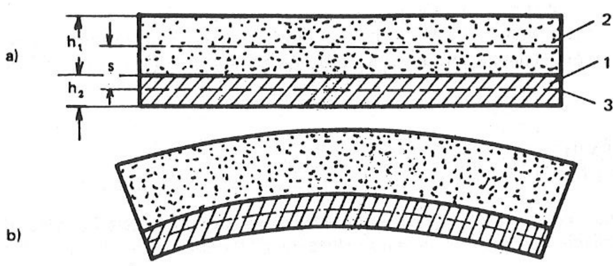

Figure 3. The board sided with the coating.
Slika 3. Ploča sa jednostranom oblogom

Basic quantities at these linings are the coefficient of damping (η_1) and elastic modulus (E_1) of the material of the base panel, coefficient of damping (η_2) and elastic modulus (E_2) of the absorbing material, and the resulting coefficient of damping (η) and the resulting elastic modulus (E) of the panel with sided lining.

The resulting coefficient of damping, depending on the elastic modulus and the thickness of coating, is calculated by using the equation

$$\eta = \eta_2 \frac{E_2 \cdot h_2 \cdot s^2}{B} \tag{1}$$

and the resulting flexion stiffness (B) by using equation

$$B = \frac{E_1 \cdot h_1^2}{12} + E_2 \cdot h_2 \cdot s^2 \tag{2}$$

where h_1 is the thickness of the base panel, h_2 the thickness of lining, and $s = \frac{1}{2}(h_1 + h_2)$ is the distance between the neutral axis.

By introducing some simplification, the above equation can be written as:

$$\eta \approx \eta_2 \frac{E_2}{E_1} \frac{h_2}{h_1} \quad \text{or} \quad \frac{\eta}{\eta_2} \approx \frac{E_2}{E_1} \frac{h_2}{h_1} \tag{3}$$

For achieving maximal damping factor by this method, sided lining should comply to the following guidelines:

- For larger damping, use a material with larger damping factor. The material commonly used has $\eta_2 = 0.5$–2.

The elastic modulus of absorption material should preferably be larger. Materials such as rubber, felt, etc. are not suitable. The elastic modules of absorption materials are of the order of magnitude $E_2 = 10^8$–10^9 N/m^2, while, the elastic modulus of steel sheet is $E_1 \approx 2.1 \times 10^{11}$ N/m^2.

- The applied absorption material should be as thick as possible. Based on practical experience it should be 2–3 times thicker than the thickness of the panel whose oscillations should be reduced.
- Damping coefficient can be significantly increased if greater distance between the neutral axis of the base panel and absorption lining is achieved. This separation is achieved by increasing thickness of the lining. From that reason absorption material should only be applied to one side of the panel. The distance between the neutral axes can be increased if between base panel and lining an extra layer is inserted, preferably with high strength, in the form of hollow handles.

Plates with different linings and multiple linings

a) Plate with covered absorptive material

This method of lining is shown in Fig. 4. The main difference is that the sided a layer of metal in the form of metal foil is applied, with a small damping coefficient of $\eta_3 \approx 0$. A new metal layer is made of the same material as the base plate.

In this method, in addition to bending load, absorption materials endure shear load, as well. Because of that, the elastic properties of absorption material are characterized by the shear modulus:

$$\overline{G}_2 = G_2(1 + j \cdot \eta_2) \quad (4)$$

which, depending on the elastic modulus, can be calculated by using equation:

$$G = \frac{E}{2(1+\mu)} \quad (5)$$

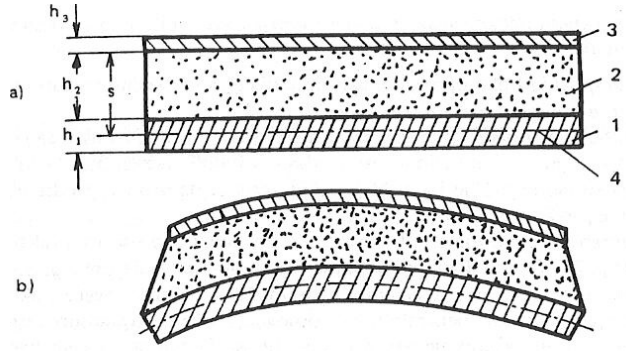

Figure 4. The base plate coupled with absorption material and a thin cover.
Slika 4. Osnovna ploča u sprezi sa apsorpcionim materijalom i tankim poklopcem

The basic characteristic of this absorption method is that the damping coefficient depends on frequency. Maximum damping coefficient (η_{max}) occurs at the frequency

$$f_{max} = \frac{1}{2\pi}\frac{G_2}{E_3}\frac{\sqrt{1+\eta_2^2}}{h_2\, h_3}\sqrt{\frac{B}{m_s}} \quad (6)$$

leading to

$$\eta_{max} = \frac{E_3\, h_3\, s^2}{B}\frac{\eta_2}{2\left(1+\sqrt{1+\eta_2^2}\right)} \quad (7)$$

For the panel of thickness $h_1 >> h_2$, $h_1 >> h_3$ and

$$B \approx \frac{E_1 \cdot h^3}{12} s = \frac{h_1}{2} \quad (8)$$

one gets

$$\eta_{max} = \frac{3}{2}\frac{E_3\, h_3}{E_1\, h_1}\frac{\eta_2}{\left(1+\sqrt{1+\eta_2^2}\right)} \quad (9)$$

Provided that the base panel and the protective cover are made of the same material, $E_1 = E_3$, and the damping coefficient of absorption material $\eta_2 = 0.8$, one gets:

$$\eta_{max} \approx 0.5\frac{h_3}{h_1} \quad (10)$$

From this analysis it is seen that this method is suitable for reducing the noise made by thick panels. In doing so, the thickness of the absorption material is of smaller importance.

Compared to the sided lining, the maximum damping coefficient (η_{max}) does not dependent on the modulus of elasticity (E_2) and shear modulus (G_2) of the absorption material. However, it is very important that the frequency at which it can be expected (η_{max}) lies in the frequency range that can be realized with the available materials of small modules (E) and (G). In this method, the material with greater η is used.

Benefits of covered linings, compared to sided linings, are as follows:

1. Materials with low elastic modulus can be used.
2. Effectively deadening thick sheets.
3. The large damping coefficient is obtained, large noise reduction with low material consumption, and a small increase in weight of machine.
4. Selective noise reduction at a particular frequency range may be achieved.

For practical dimensioning of covered absorbing linings the following panel thickness (h) and damping coefficient (η) is recommended, Table 1.

Table 1. Recommended plate thickness and extinction coefficient.
Tabela 1. Preporučene debljine ploča i koeficijenta prigušenja

h_2	h_3	η
0.5 h_1	(0.05–0.1) h_1	0.05
h_1	(0.05–0.1) h_1	0.1

b) Two panels of the same thickness with a thin interlayer

Figure 5 shows the principle of the structural solution of vibration absorption in two panels of the same thickness, with a thin absorption interlayer.

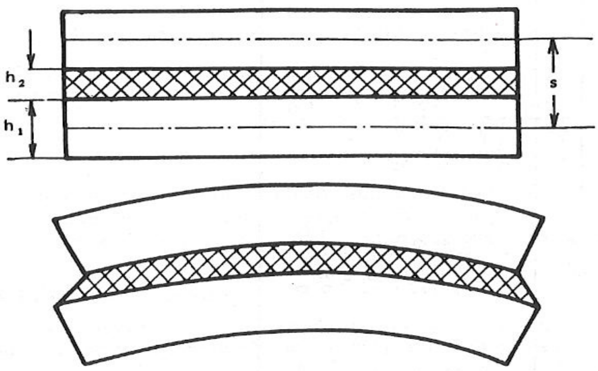

Figure 5. Two plates with a thin interlayer.
Slika 5. Dve ploče sa tankim međuslojem

DAMPING COEFFICIENT OF PANELS

By using the previously mentioned possibility of absorption of materials, as well as the possibility of changing the initial values of the mechanical properties of the base material, which in this case is the reinforced concrete (as composite materials), /3-6/, results are obtained and shown in Fig. 6.

For both variants the thickness of the panel is changed, which is defined in Fig. 6 as the ratio h_1/h_2 (the first version) and the ratio h_1/h_3 (the second version), for 10 different values. The highest ratio, h_1:h_2 = 1:10, is giving the highest values of the damping coefficient, number 1 in Fig. 6, and further decreased to ratio 1:1, where the increase damping coefficient is minimum (marked with number 10). The same is done with the ratio h_1/h_3, with note that such large differences cannot be used effectively; anyhow even lower values for the version 2 (1:2, 1:3) are larger than for the first version.

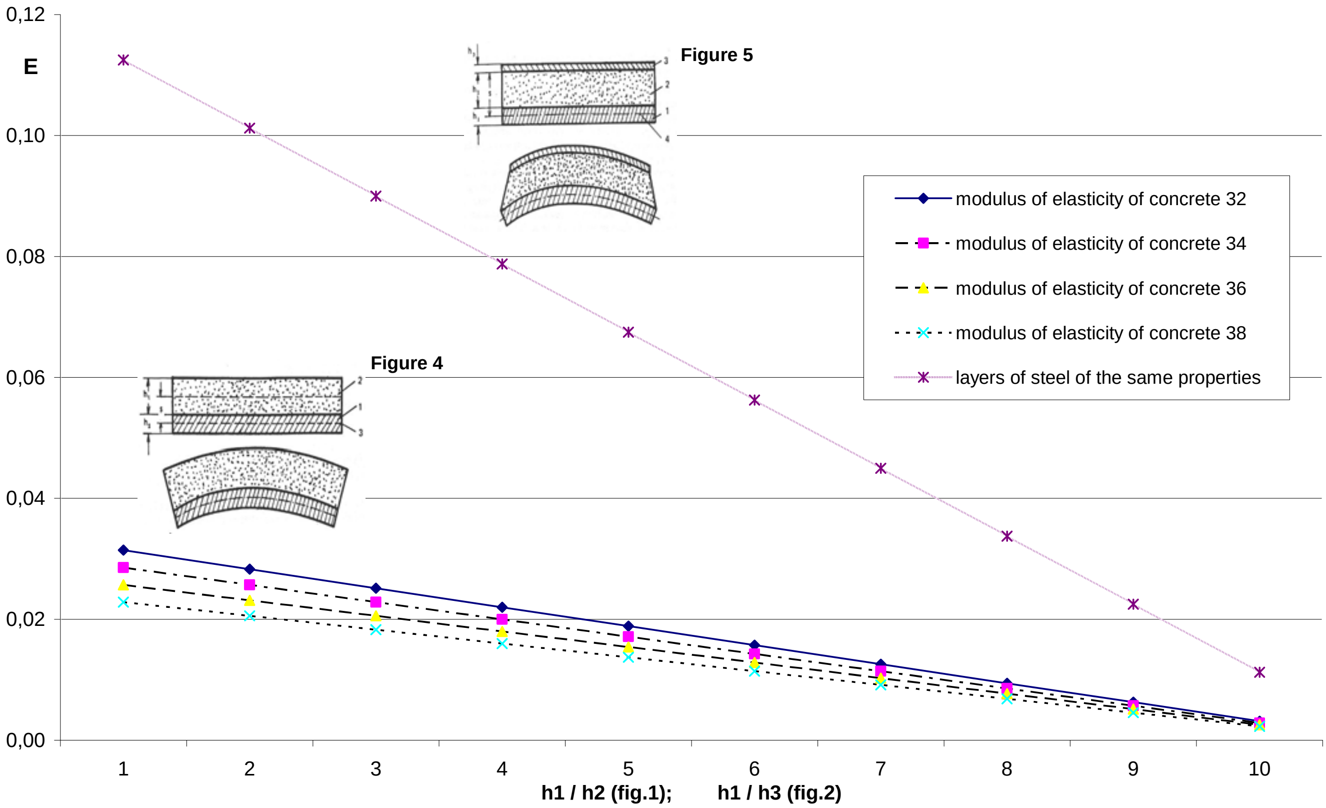

Figure 6. The coefficient of damping plates coated with composite material iron–concrete.
Slika 6. Koeficijent prigušenja ploča sa oblogom od kompozitnog materijala gvožđe–beton

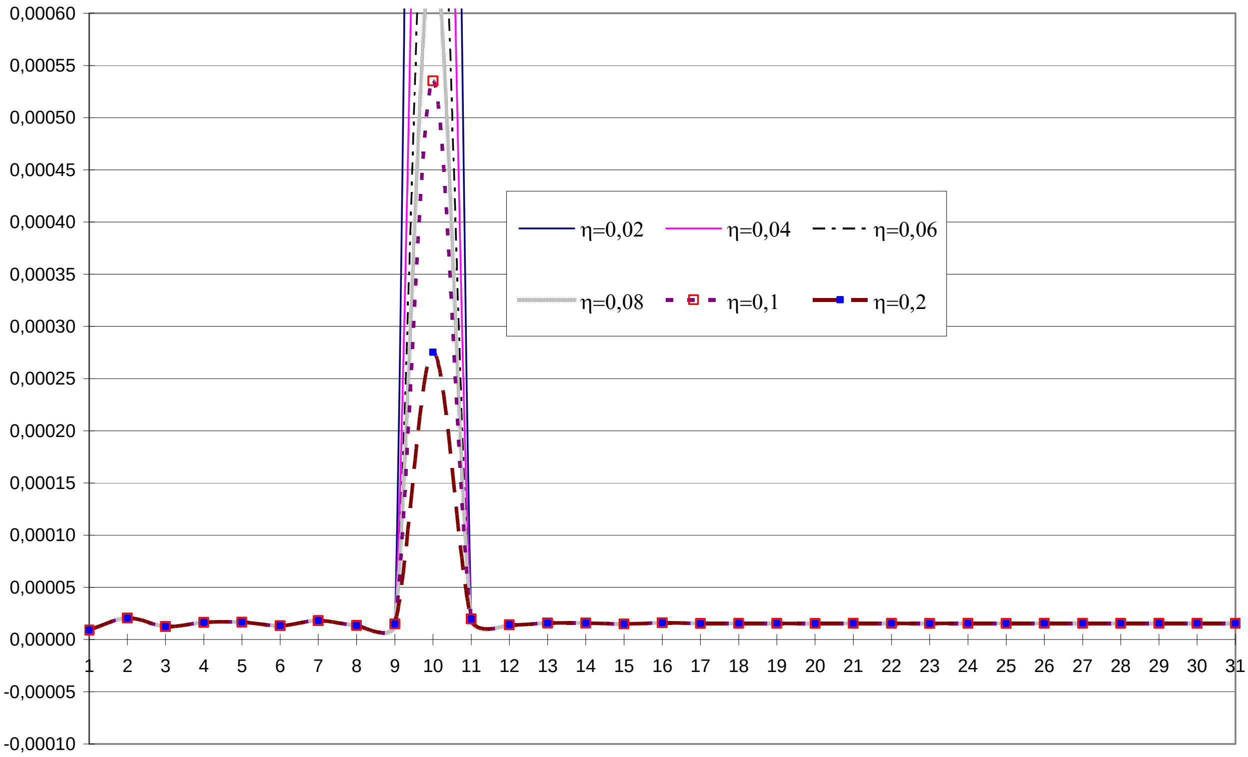

Figure 7. Diagram of the extinction coefficient on the impact of horizontal displacement of poles.
Slika 7. Dijagram uticaja koeficijenta prigušenja na horizontalno pomeranje stubova

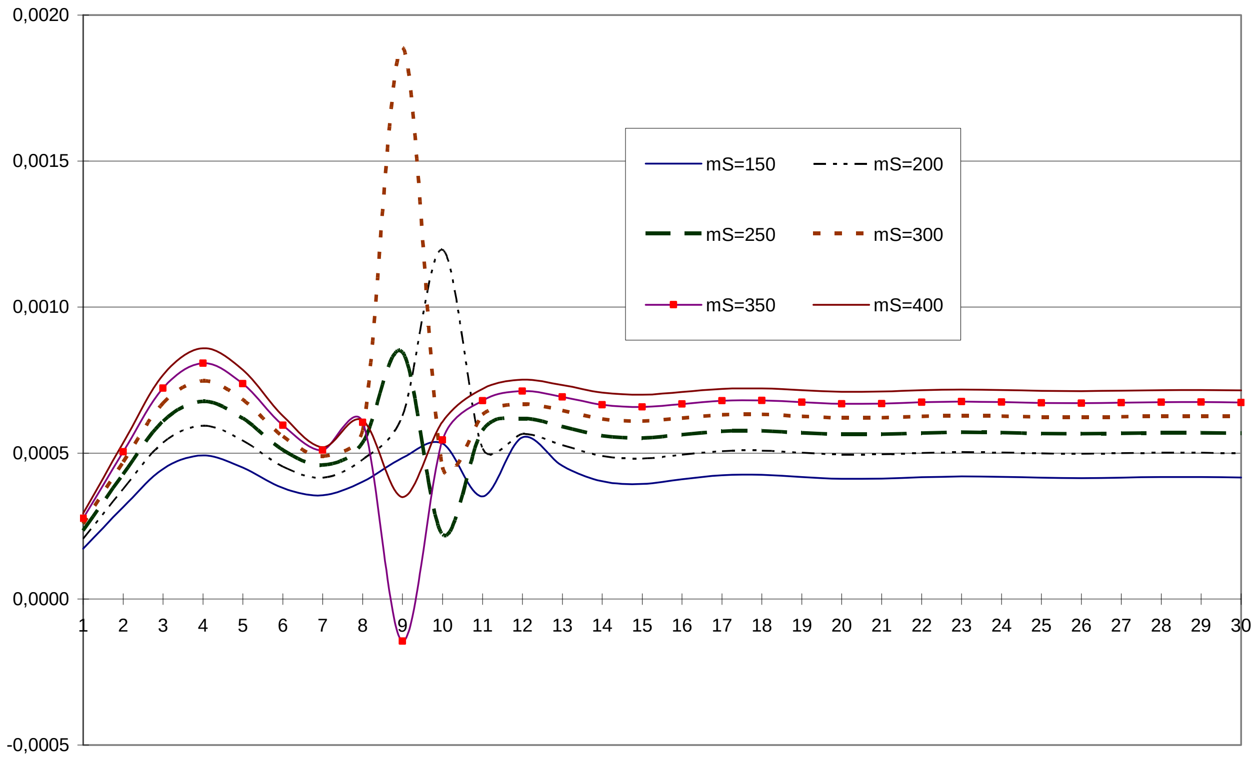

Figure 8. Diagram of the effect of mass movement to trim the pillars in the vertical direction.
Slika 8. Dijagram uticaja mase stubova na pomeranje traverze u vertikalnom pravcu

It can be seen that, for the variant 1, with only one panel, lower values of total damping coefficient are obtained. It clearly shows the influence of the characteristics of reinforced concrete, for which it was previously proven that it can be easily changed by changing the concentration of reinforcement, i.e. fibres in a matrix of concrete.

For variant 2, the covering with two panels, the influence of composite materials is negligible, but the ease of use of concrete in the construction and large increase of damping coefficient of the whole structure, is taken as an opportunity for designing of the supporting structure. It should be noted that this option is beneficial because lower mechanical properties of the concrete are more than compensated by large increases of damping coefficient.

By applying results obtained by calculation and shown in Fig. 7, e.g. for the supporting structure in Fig. 1, and its dynamic model in Fig. 2, one gets the behaviour diagrams, i.e. shifts depending on the damping coefficients and mass of the support structure components. In Fig. 8 a large influence of damping coefficient on moving pillars in the horizontal direction is seen, while the influence of damping coefficient decreases and influence of the weight increases when the cross bar is moving in the vertical direction.

After such an analysis of the possibility of changing material characteristics, it is clear that one can obtain a wide range of results, enabling also the re-analysis of results, /7, 8/. In the field of dynamic behaviour of support structure, with the calculation of amplitudes of moving parts, the possibility to change input parameters, i.e. material characteristics, provides high potential for obtaining a variable number of constructive solutions. When work load is considered, /9/, for which the machine is intended, i.e. size of forced oscillations, one can talk about a really large number of design solutions for supporting structure. In this case, the size of structural holes is not taken into account, /10/, as well as the impact of additional elements that are eventually located on the support structure.

CONCLUSION

Based on given examples, and taking into account all analyzed applications of composite materials for support structure of the machine, one can conclude that increased possibility for their application has been proved.

In addition to simple construction, there are two more advantages of concrete-steel composite material: relatively low, and the ease of changing of its characteristics. By small changes in the content of steel fibres in a matrix of concrete, one gets a composite material with a very wide range of mechanical properties and damping coefficients, which are very important for the absorption of vibrations and dynamic behaviour of support structure of the machine.

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