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IMPACT OF CERTAIN ENGINEERING METHODS ON RESULTS OF COMPUTATIONAL ANALYSES OF ROLLING GUIDEWAY SUBASSEMBLIES

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S u m m a r y

The paper demonstrates results of computational analyses of static properties of a single rolling subassembly. Varied engineering methods were applied to model the subassembly in question. When selecting these methods, a goal was to limit dimensionality and complexity of a model. Conducted analyses were based on a finite-element method along with GS method (external loads correction). For needs of the analyses there were applied variants of a model developed in a form of rigid and deformed finite elements, as well as hybrid variants combining ideas of both of the methods into a single hybrid model. Particular variants of the model were characterized by varied levels of simplifications concerning form and deformation of a body of a bearing cage and a linear guide. Impact of permanent connection points in a model or their exclusion existing between assembly areas of the cage and rail and bodies of guide systems was analysed.

Keywords: modeling, finite-element method, rolling guideway subassemblies

Wpływ techniki modelowania na analizę obliczeniową tocznych podzespołów prowadnicowych

S t r e s z c z e n i e

W pracy przedstawiono analizę obliczeniową właściwości statycznych pojedynczego podzespołu tocznego. W modelowaniu podzespołu stosowano różne metody modelowania. Ograniczenia wymiarowości i złożoności modelu były kryteriami ich doboru. Podstawą prowadzonej analizy była metoda elementów skończonych uzupełniona metodą GS (korekcji obciążeń zewnętrznych). W analizie stosowano warianty modelu opracowane w konwencji metody sztywnych i odkształcalnych elementów skończonych. Wprowadzono także warianty hybrydowe łączące obie te metody. Warianty modelu różnią się poziomem uproszczeń dotyczących kształtu i odkształcalności korpusu wózka tocznego i szyny prowadzącej. W badaniach uwzględniono także wpływ wprowadzania do modelu silnie zaciśniętych połączeń stałych, między powierzchniami montażowymi wózka i szyny oraz korpusami zespołów prowadnicowych.

Słowa kluczowe: modelowanie, metoda elementów skończonych, toczne podzespoły prowadnicowe

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1. Introduction

Guide subassemblies such as bearing cage the are commonly used in technological machinery as basic parts of structure of guide elements. For needs of the technological machinery designing process, there are commonly applied computational analyses which enable determination of properties of such machinery. Proper reliability of such analyses can be acquired by means of adjusting some engineering of particular subassemblies of the machinery, including rolling guideway subassemblies to the intended goal. However, because of the frequency of existence of such subassemblies within a single machine it is justified to search for simplifications at the stage of process modeling process, which do not have an impact on final results. Analyses demonstrated in this paper focus on such aspects as: simplification of geometric form, change of a mesh density, replacement of tight permanent connections with structures maintaining continuity of a material and application of different variants (hybrid models) in terms of deformation of a ball bearing cage's body and a linear guide.

2. The subject of examinations

The subject of analyses was a caged ball guide THK – type SVR 25RW (Fig. 1), which is commonly applied within guide systems of contemporary machine tools [1].

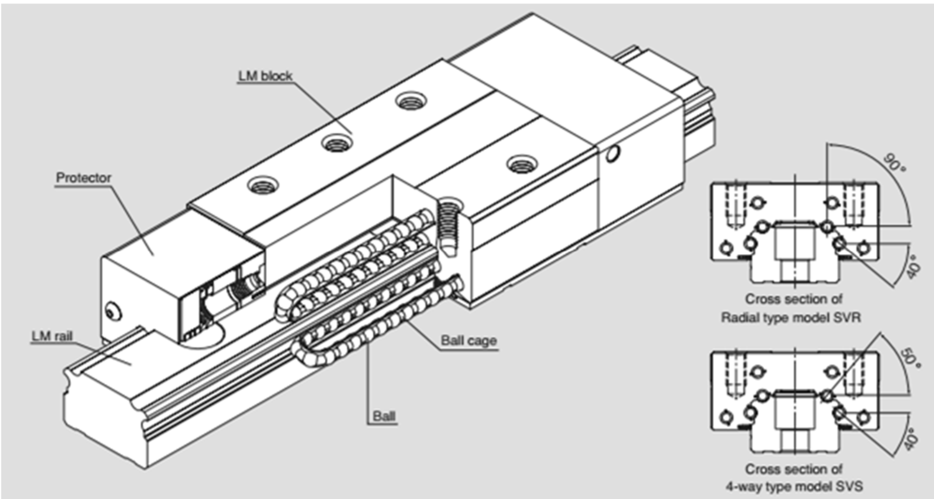

Fig. 1. Caged ball guide THK SVS/SVR 25RW

3. Computational methods

The most frequent methods applied in the process of designing computational analyses of rolling guideway subassemblies are rigid (RFEM) and deformable finite-element methods (DFEM). In the case of DFEM, digitizing of every single ball element is carried out (Fig. 2a). Because of the shape of a rolling element itself, as well as the area of a track and number of these elements in a single subassembly, such procedure may lead to models characterized by serious dimensionality. In practice, this feature excludes application of this sort of engineering of subassemblies for needs of calculations of the entire structure of machinery.

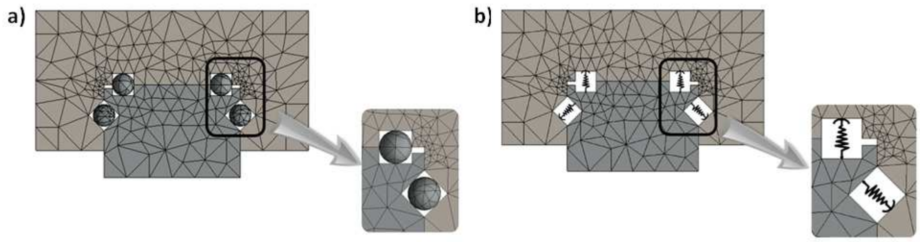

Fig. 2. Engineering of: a) ball elements according to deformable finite-element method, b) rolling subassemblies with spring elements

Because of the complexity of the ball subassembly model designed according to the FEM, in this paper we propose an approach based on the agreed replacement of impacts of single ball elements along with contact tracks with spring elements (Fig. 2b). Application of such elements in the model in extent of analyses of static properties, required application of the external loads correction method [2-6].

According to the applied methodology, two structures in the model were separated: the body structure and the contact one. The first of them comprises all body elements. This part of the structure was modeled according to the finite-element method – rigid or deformable ones. Hybrid models were also applied; in a single model at the same time two modeled fields were applied – deformable and perfectly rigid one. In turn, in the framework of the second structure, formability of a single rolling element and its areas of cooperation with tracks was replaced with a spring element of one-side characteristics of the spring attribute (Fig. 3). Such a spring contact elements are able to operate only under compression loads, and in the case they are loaded into tensile direction they lose their capability to transfer loads. Spring elements of two-side operation characteristics (compression and tensile operations) were included in the contact structure. The elements in question were applied to model fixing screws for permanent connections.

Integration of both model structures required development of models assuring compatibility of location of nodes of contact elements with nodes of deformable elements. This compatibility was obtained by means of the mesh generation process control in particular models.

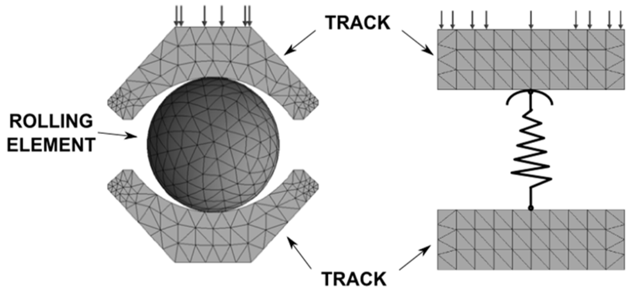

Fig. 3. Engineering of cooperation between a rolling element and tracks:
a) by a deformable finite-element method, b) by means of a contact spring element

Models were developed in SolidWorks software environment. In turn, calculations were conducted by means of a specialized software intended to calculate structures of machine tools based on the external loads correction method, performed conducted in the Institute for Mechanical Technology of West Pomeranian University of Technology in Szczecin [3-5].

4. Results of the calculations

The most frequently applied tests in the analyses of static properties of guide systems of machine tools are those which enable obtaining characteristics of stiffness rates variability. Values of the rates in question are determined in certain points of a structure.

There was also conducted series of analyses regarding numerous variants of developed models. Characteristics of displacements at the load application point depending on the value of the load were determined. On the basis of the aforementioned results there was listed and assessed impact of the applied engineering methods on results of conducted computational analyses.

The first analysis was comparison of runs acquired by means of deformable (DFEM) and rigid (RFEM) finite-element methods. In the case of results acquired for the RFEM method, determined displacements arise exclusively from susceptibility of contact finite elements modeling rolling elements. In turn, results obtained for the DFEM method should also include formability of body elements. In both cases, when keeping identical parameters describing spring properties of a contact structure, difference concerning obtained results constitutes value of displacements arising from formability of solid structure are presented in Fig. 4.

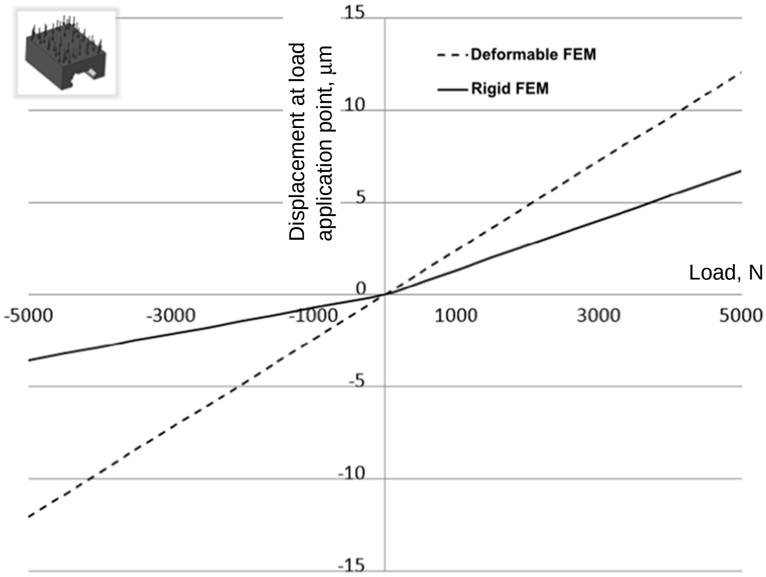

Fig. 4. Comparison of results for rigid and deformable finite-element method

During analyses attention was paid to the fact that complicated geometric form of a cage requires digitizing, which extends computation time and significant dimensionality of a model. Consequently, models of simplified geometric form were developed and proper calculations were conducted for them. For needs of this analysis there were carried out four variants of geometric form of a cage, from the most similar to the real geometry to the simplest one. Because of very small difference of displacements determined for particular variants, it seems to be justified to apply simplified variants, however, with potential omission of the simplest variant, for which obtained results were the most different from the non-simplified variant (Fig. 5).

In the Fig. 6 there were listed computation times corresponding to variants of simplifications of the geometric form of the bearing cage model. In the Fig. 6 one can notice that application of simplifications significantly reduces number of nodes of a model and cuts computation time more than three times compared to results acquired for the least simplified variant.

During the following analysis there was examined an impact of application of varied mesh density of the bearing cage body on deformable elements and values of calculated displacements. In the Fig. 7 results of the analysis in question are listed; one can observe stabilization of investigation of characteristics variability as the mesh density grows up. On the basis of these results one may suppose that in the case of extended density the investigation will continue getting stabilized and consequently, generate smaller and smaller displacement differences. It comes about a phenomenon of a certain kind of "saturation" of the investigation. On this basis there was made an assumption that it is possible to determine optimal mesh density enabling acquisition of reliable results within the relatively short time.

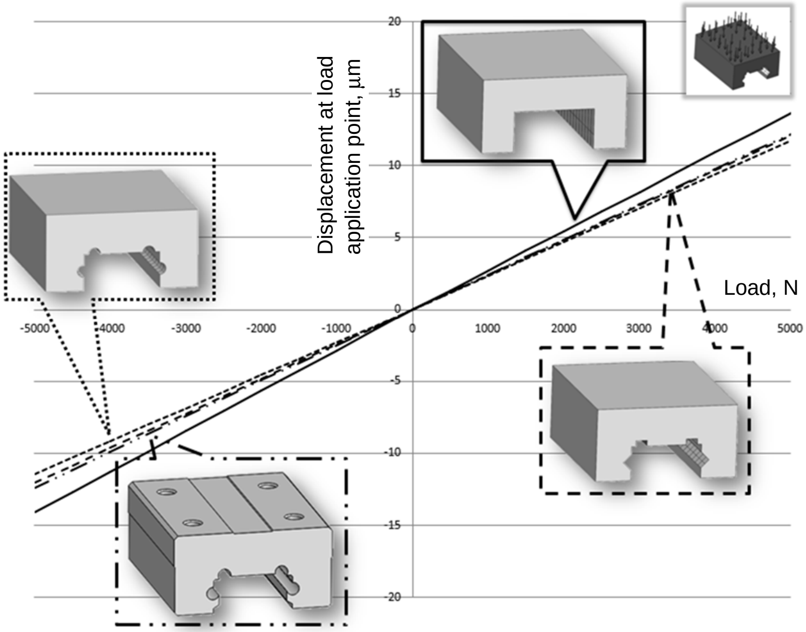

Fig. 5. List of results acquired for numerous variants of simplifications of geometric forms of the bearing cage model

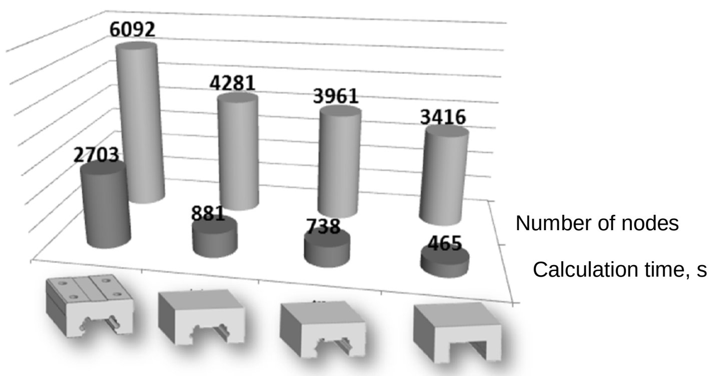

Fig. 6. Comparison of computation times for numerous variants of geometric forms of the bearing cage model

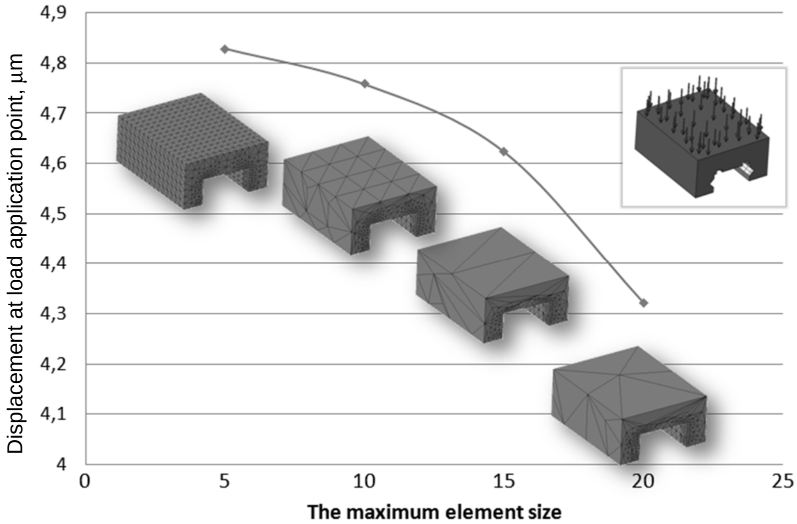

Fig. 7. Impact of mesh density on values of displacements at place where force is applied

Bearing cages are connected with elements of structure of machine tools by means of the specially prepared assembly area. This area makes a tight twisted connection, along with proper area of a sliding system. In the case of the subassembly under examination the "grip" is provided by means of four M6 screws (Fig. 8). According to recommendations of the manufacturer, these must be screws characterized by the increased strength, type 12.9.

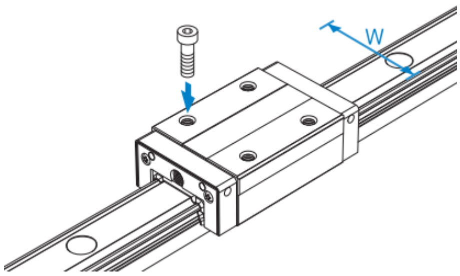

Fig. 8. The way in which elements of the structure are connected with a guide cage

In the case of the GS this connection was engineered by the classic [2] method. Contact elements modeling contact to both of the areas. However, screw the connection was replaced with double-side operation spring elements which enable entering preliminary clamps into the model. As an alternative engineering way there was applied variant where the regular connection was replaced with a structure maintaining continuity of the material. The Figure 9 demonstrates idea of the permanent connection engineering.

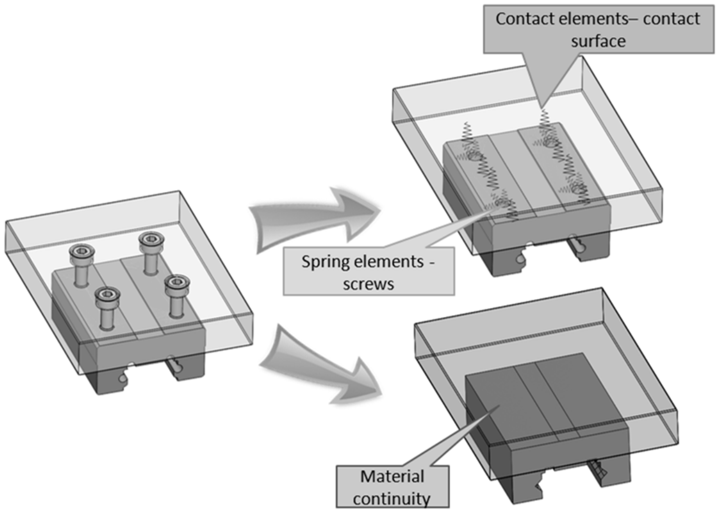

Fig. 9. Variants of engineering of permanent connection of a bearing cage with a structural element of a machine tool

During calculations there was examined an impact of values of preliminary clamps existing in fixing screws on displacements of the structure. In the Fig. 10 there were listed results for different levels of preliminary clamps existing in fixing screws of ball cages.

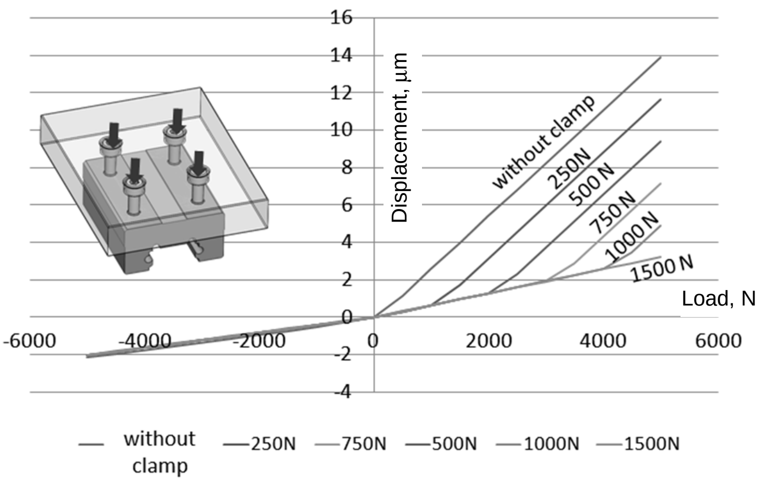

Fig. 10. Test of value of clamping force of twisted connection

In the Fig. 10 it can be observed that there is no impact of a clamp value on the calculated displacement in the case of clamping force value exceeding 1500 N on every screw. One can observe that this value is much lower than a permissible one for applied fixing screws recommended by a manufacturer. For needs of following considerations, the accepted value equaled 2000 N in order to keep extent of safety.

Results acquired during previous calculations were applied to examine possibility to replace permanent connection with alternative variant of the model where permanent connection was omitted. It was carried out by application of a single solid element geometrically corresponding to a cage and a fragment of a structure of the sliding system. For both variants of the model there was calculated displacement of the structure at a force application place. In the Fig. 11 characteristics of structure displacement are demonstrated depending on the value of loading force. Comparing obtained characteristics one may conclude that application of this sort of simplification is justified.

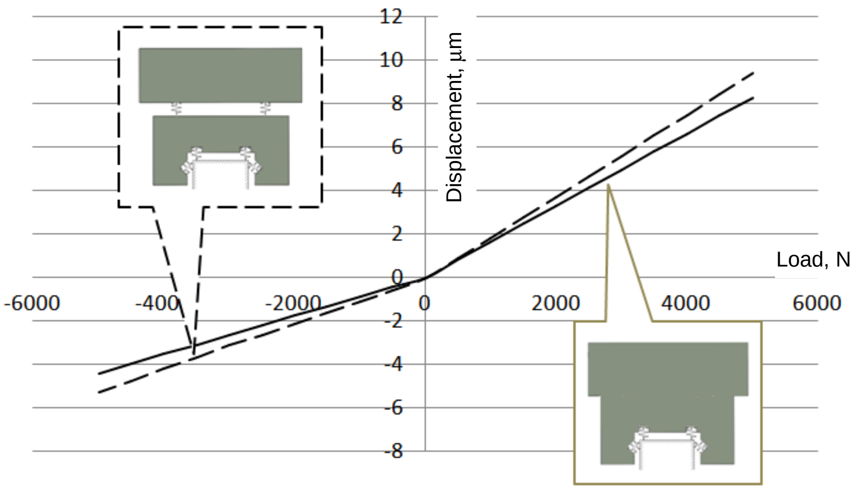

Fig. 11. List of displacement characteristics for variants of the model: with tightly clamped permanent connection and a variant based on continuity of a material

Next analysis included previously accepted simplifications and four variants of the model of the entire rolling guideway subassembly were developed. The model comprised a fragment of a rail and a solid geometrically corresponding to a cage and fragment of a sliding system structure. All of the variants were based on a perfect stiffness. A deformable variant was developed in the case of which the entire solid structure was treated as a deformable one. Alternatively, in the rigid variant, solid structure was based on a rigid finite element. Moreover, two hybrid variants were developed. In the case of the first of them, perfect stiffness of a fragment, which corresponds to the cage, was assumed as well as formability of the remaining part (hybrid 1). In the second variant, there was assumed formability which geometrically corresponds to a cage as well as stiffness of the remaining part (hybrid 2). In the Fig. 12 there were listed results of conducted calculations. Symbolic figures corresponding to particular variants of the model are assigned to particular characteristics.

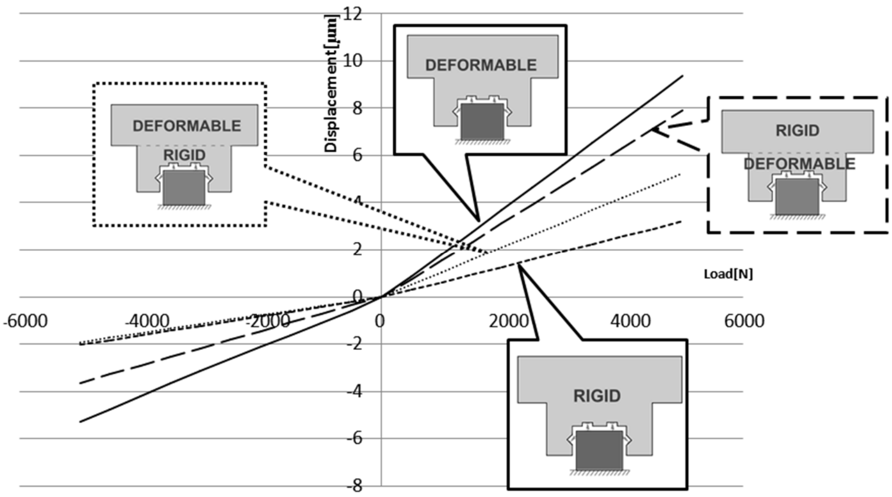

Fig. 12. Comparison of displacement values for variants: deformable, rigid and hybrid

Presuming that results acquired for the deformable variant describe the behavior of rolling subassemblies in the best way, it must be concluded that results for the variant marked hybrid 2 (in the Fig. 12 – rigid and deformable) are similar to the deformable variant. Application of such a form of a model can be suggested for the analyses of entire structures of machine tools.

5. Conclusions

Demonstrated results of analyses enabled disclosure of differences arising from application of particular modeling methods. Application of presented solutions enabled decreasing in dimensionality of analyzed models. Assessment of results of conduced analyses for considered variants of ball models of guide subassembly enables determination of range of usability in relation to requirements of designing-structural process of contemporary technological machinery.

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