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Analysis of properties of automotive vehicle suspension arm depending on different materials used in the MSC.Adams environment

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ABSTRACT

Purpose: Under the study discussed in the paper, a geometric model of a car's suspension arm was prepared and subsequently imported into the MSC.Adams environment dedicated to studying dynamics of multi-body systems and then broken down into finite elements. Modal frequencies were established for the said model. The superior purpose of the study was to determine the loads affecting an arm operating in a complete car's suspension system for the road-induced input functions simulated in the Adams/Car module.

Design/methodology/approach: Under the study in question, a geometric model of a car suspension arm was developed based on CAD software. The model was imported into the Adams/View environment and its body changed from rigid into a flexible one. Materials were defined and modal frequencies were established for the model prepared.

Findings: The study outcome is an FEM-based suspension arm model and the modal frequencies established. The suspension arm model in question is to be applied in further numerical experiments related to studying dynamics of automotive vehicle suspension systems.

Research limitations/implications: The numerical experiment results discussed in the paper require that the model should be adjusted to a real element. This, in turn, requires modal analysis of the suspension arm and comparison of the vectors describing the forms of free vibrations.

Originality/value: The model developed will be applied as a flexible element in a complex suspension system of a complete car and used to determine its dynamic loads.

Keywords: Arm; Flexible body; Multi body system

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METHODOLOGY OF RESEARCH, ANALYSIS AND MODELLING

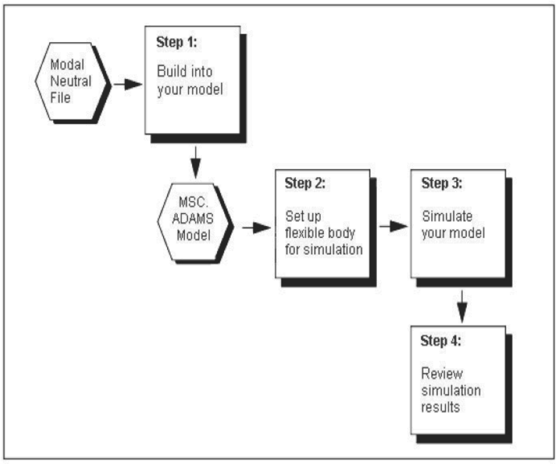
1. Introduction

The ADAMS software is a commercially available set of applications which enables creating structural multi-body systems of a considerable number of degrees of freedom based on elements of concentrated masses, and it provides dedicated applications divided into industry-specific modules, e.g. railway, aviation or automotive industry. Using such software, models are built assuming that the given system is composed of rigid or deformable (flexible) bodies combined in a specific manner (spherical, sliding, rotary joints) and moving under the impact of various types of forces and moments (concentrated or distributed forces, contact forces). It is dedicated to solving tasks related to system kinematics (determination of motion of individual bodies) and dynamics (determination of system motion with non-limiting constraints of all degrees of freedom entailing the masses and forces affecting the system). It enables automatic generation of equations of motion by application of the second kind of Lagrange's method on absolute coordinates for complex systems. Integrating procedures applied to solve differential and algebraic equations may be divided into two groups. The first one comprises multi-step algorithms of variable order as well as those of variable and constant step. The second group comprises one-step algorithms, from among which the ADAMS software applies the Runge-Kutta-Fehleberga (RFK45) method. The Adams/Car module enables building and simulation-based examination of individual car subsystems such as, for instance, the suspension, steering or driving system as well as their combinations forming a complete car. The programme contains an extensive library of structural solutions applied in cars. The geometry and relationship data of individual components are stored in libraries, and software operation on a standard user level can be brought down to defining positions of constraints in space.

The software is compatible with various CAD programmes, thus enabling import of elements created in other applications. The structural solutions currently being prepared on the design stage are practically only developed in software aided processes in which numerical computational models are built to determine such physical properties as strength and deformations [1, 2, 3].

The numerical and analytical investigations performed are aimed at developing models that make it possible to analyse the operation of a structure at the preliminary design stage. Further development of numerical methods of analysis allows for simulation tests of complex multi-body systems as early as at the design stage. And this, in turn, enables assessment of dynamic properties of elements such as frequency of free vibrations and their forms. Using numerical simulations considerably contributes to detecting a system's weak links, and based on the information obtained, enables improving the system's dynamic properties at the design stage. Such an approach is characterised by cost-effectiveness, limited time consumption and the possibility of introducing considerable modifications to the system design. Moreover, it enables analysing multiple variants of structural solutions and choosing the optimum one in terms of dynamic properties and minimisation of manufacturing costs.

One of the Adams software modules used in the studies in question was Flex (Fig. 1). Adams/Flex uses an assumed modes method for modelling of flexible bodies. This method of representing flexible bodies is called modal flexibility. Modal flexibility assigns a set of mode shapes (frequently eigenvectors) to a flexible body. The flexible body modelling element designates a system state variable to each eigenvector and calculates the relative amplitude of each eigenvector during a time analysis. The principle of linear superposition is then used to combine the mode shapes at each time step to reproduce the total deformation of the flexible body. Flexible body MSS combines the advantages of the FEA and MBS analysis. Finite element analysis (FEA) offers excellent modelling capabilities for individual components in isolation but is too inefficient for system level modelling and is incapable of analysing large motion. Rigid body mechanical system simulation (MSS) efficiently analyses large motions of complex systems and can be used to generate component loads for FEA [4].



Adams/Flex Steps

Fig. 1. Adams/Flex module working diagram

Using ADAMS/AutoFlex with MSC.ADAMS products eliminates the need to use external finite element analysis (FEA) programmes. Instead, you can generate flexible bodies within the MSC.ADAMS environment, and then use ADAMS/Flex to analyse the flexible bodies to obtain over-listed results, which would otherwise have to be built in an external FEA environment and imported into MSC.ADAMS.

2. Building a geometric car suspension arm model

This paper provides an analysis of the part of the studies in question which pertained to one of the car suspension system components, namely the arm. A suspension arm is the element coupling the wheel hub (steering knuckle) with the car body. It is used to transfer considerable forces to the vehicle while it is starting to run, accelerating, braking and turning. Depending on the method used to mount it and to control the wheel, the suspension arm can be arranged in a transverse, longitudinal or oblique manner. The suspension arm is coupled with a frame by means of metal and rubber sleeves, being a solution enabling certain small shifts of the arm (suspension system elastokinematics) and influencing the damping of vibrations resulting from the road profile.

Suspension arms are usually manufactured by casting iron or light alloys (aluminium) or by forging steel.

The arm model examined was a McPherson type, independent front suspension arm from Fiat Seicento. The element's geometric model was developed in the Inventor environment (Fig. 2).

Subsequently the model was imported into the Adams/View environment as a rigid body. Naturally, this environment also enables creating geometry, however, compared to CAD type software dedicated to creating geometry of elements, the interface and capabilities of the Adams/View environment are considerably limited. The model imported into the Adam/View environment has been depicted in Fig. 3.

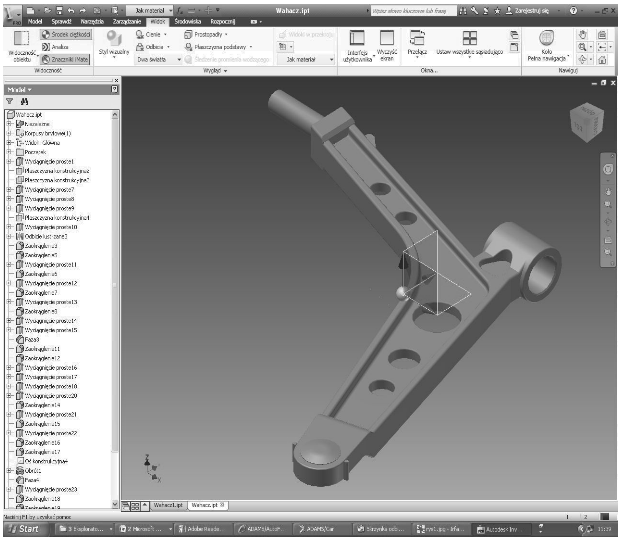


Fig. 2. Suspension arm model developed in the Inventor environment

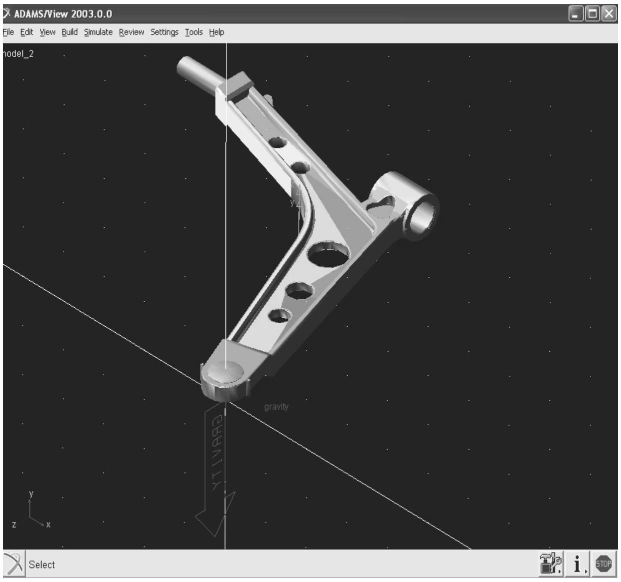
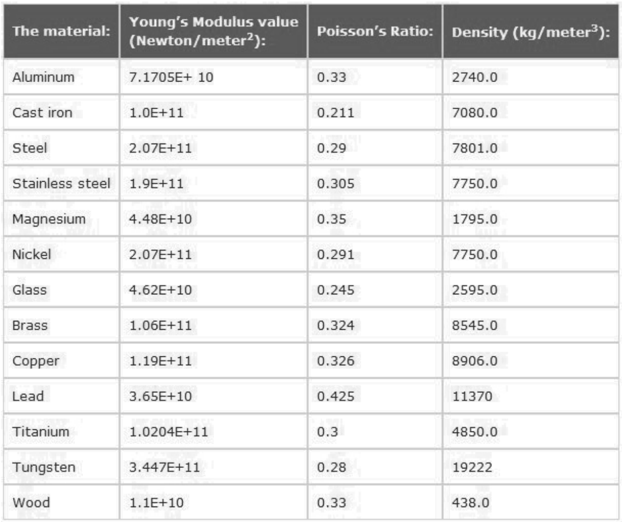


Fig. 3. Suspension arm model imported into the Adams/View environment

3. Material properties assumed

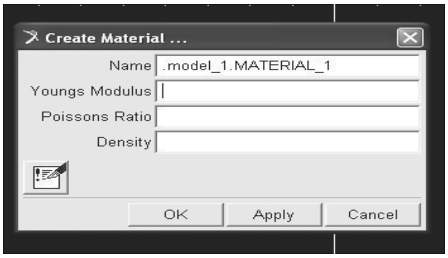
Material properties are very important for vehicles structure. There are many publications on novel technologies for clear materials production [7-9, 11-13]. It is important how reparation process influence on the properties, for example after welding process [10]. In the next stage, material was defined to be used for imaging of the suspension arm. All material types in ADAMS/View (Fig. 4) are assumed to be linearly elastic. ADAMS/View automatically calculates the material's shear modulus (G) from Young's modulus (E) and Poisson's ratio



The material:	Young's Modulus value (Newton/meter^2):	Poisson's Ratio:	Density (kg/meter^3):
Aluminum	7.1705E+ 10	0.33	2740.0
Cast iron	1.0E+11	0.211	7080.0
Steel	2.07E+11	0.29	7801.0
Stainless steel	1.9E+11	0.305	7750.0
Magnesium	4.48E+10	0.35	1795.0
Nickel	2.07E+11	0.291	7750.0
Glass	4.62E+10	0.245	2595.0
Brass	1.06E+11	0.324	8545.0
Copper	1.19E+11	0.326	8906.0
Lead	3.65E+10	0.425	11370
Titanium	1.0204E+11	0.3	4850.0
Tungsten	3.447E+11	0.28	19222
Wood	1.1E+10	0.33	438.0

Fig. 4. Properties of materials available in the Adams software

The programme also enables defining one's own material for which the following parameters must be given: density, Young's modulus and Poisson's ratio (Fig. 5).



Name .model_1.MATERIAL_1
Youngs Modulus
Poissons Ratio
Density

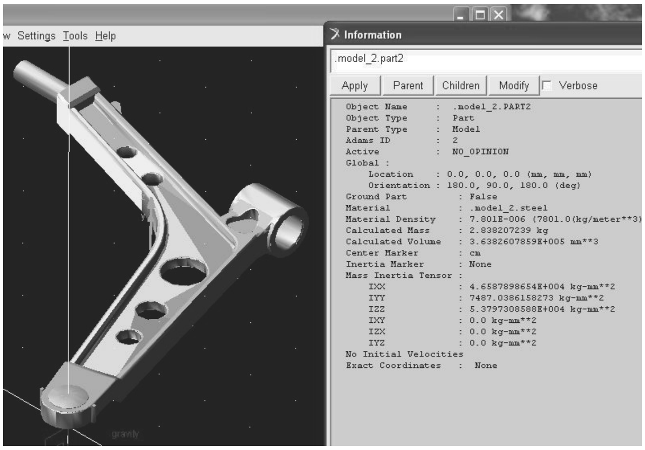
Fig. 5. Defining new material in the Adams software

For the material envisaged in the programme, mass and volume parameters are defined for the given element as well as the location of the centre of gravity and moments of inertia.

ADAMS/View uses two different methods to calculate mass properties. ADAMS/View may use a different method to calculate the element's mass properties depending on the number of sides. If the number of sides is larger than or equal to the default number of sides (usually 20), ADAMS/View calculates the mass using an analytical equation for the geometry volume.

If the number of sides is smaller than the default, ADAMS/View uses a prismatic solid to calculate mass properties [5].

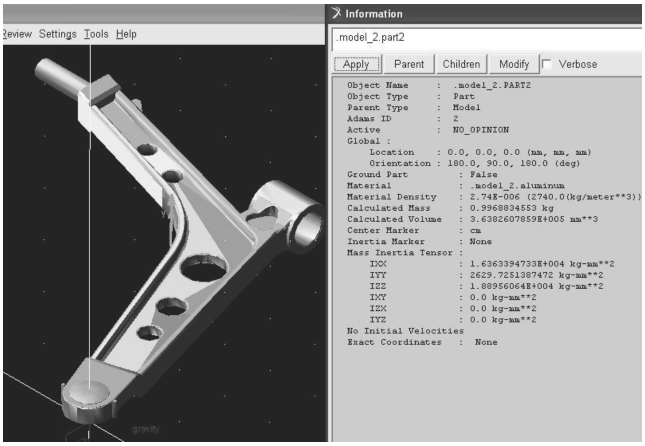
Other quantities being calculated include moments of inertia and cross products of inertia. Mass parameters and moments of inertia for a suspension arm made of steel have been illustrated in Fig. 6, whereas those for an arm made of aluminium – in Fig. 7.



```
.model_2.part2

 Object Name      :  .model_2.PART2
 Object Type      :  Part
 Parent Type      :  Model
 Adams ID         :  2
 Active           :  NO_OPINION
 Global :
     Location     : 0.0, 0.0, 0.0 (mm, mm, mm)
     Orientation  : 180.0, 90.0, 180.0 (deg)
 Ground Part           : False
 Material              : .model_2.steel
 Material Density      : 7.801E-006 (7801.0(kg/meter**3)
 Calculated Mass       : 2.838207239 kg
 Calculated Volume     : 3.6382607859E+005 mm**3
 Center Marker         : cm
 Inertia Marker        : None
 Mass Inertia Tensor   :
     IXX               : 4.6587898654E+004 kg-mm**2
     IYY               : 7487.0386158273 kg-mm**2
     IZZ               : 5.3797308588E+004 kg-mm**2
     IXY               : 0.0 kg-mm**2
     IZX               : 0.0 kg-mm**2
     IYZ               : 0.0 kg-mm**2
 No Initial Velocities
 Exact Coordinates     :  None
```

Fig. 6. Mass parameters and moments of inertia for a steel suspension arm



```
.model_2.part2

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 Object Type      :  Part
 Parent Type      :  Model
 Adams ID         :  2
 Active           :  NO_OPINION
 Global :
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     Orientation  : 180.0, 90.0, 180.0 (deg)
 Ground Part           : False
 Material              : .model_2.aluminum
 Material Density      : 2.74E-006 (2740.0(kg/meter**3))
 Calculated Mass       : 0.9968834553 kg
 Calculated Volume     : 3.6382607859E+005 mm**3
 Center Marker         : cm
 Inertia Marker        : None
 Mass Inertia Tensor   :
     IXX               : 1.6363394733E+004 kg-mm**2
     IYY               : 2629.7251387472 kg-mm**2
     IZZ               : 1.88956064E+004 kg-mm**2
     IXY               : 0.0 kg-mm**2
     IZX               : 0.0 kg-mm**2
     IYZ               : 0.0 kg-mm**2
 No Initial Velocities
 Exact Coordinates     :  None
```

Fig. 7. Mass parameters and moments of inertia for a steel suspension arm

4. Analysis of free vibrations

Free vibrations of systems, also known as proper vibrations, are particularly important when building machines and vehicles. One should avoid such phenomena as structure resonance, i.e. overlapping of a system's excitation frequency and free vibration frequency. In paper [6] it can be found some vibration research on vehicle elements made from different materials.

Applying a load of vibration frequency equal to resonant frequency of a machine or one of its elements leads to uncontrolled increase of the vibration amplitude and may cause the structure to be destroyed.

Using the Adams/Flex module under the studies in question, the suspension arm model, being a rigid body, was subjected to discretisation and substituted with a flexible element model (Fig. 8).

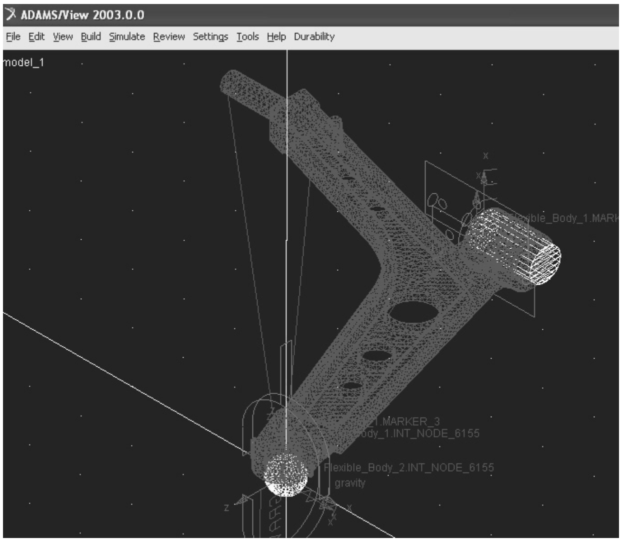
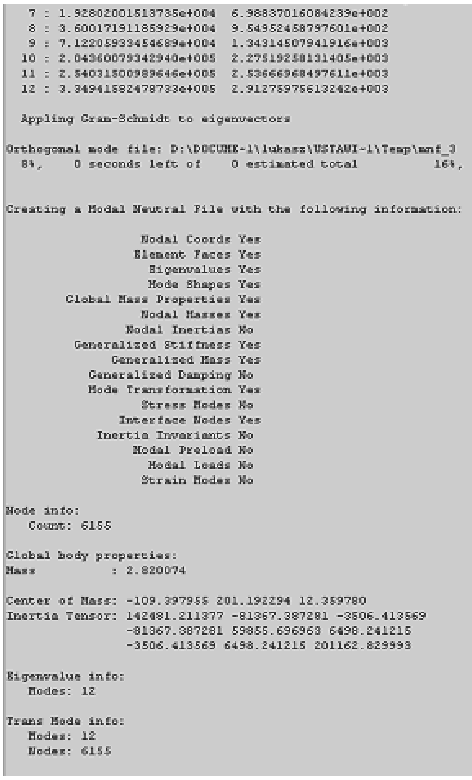


Fig. 8. Suspension arm model as a flexible element in the Adams/View environment

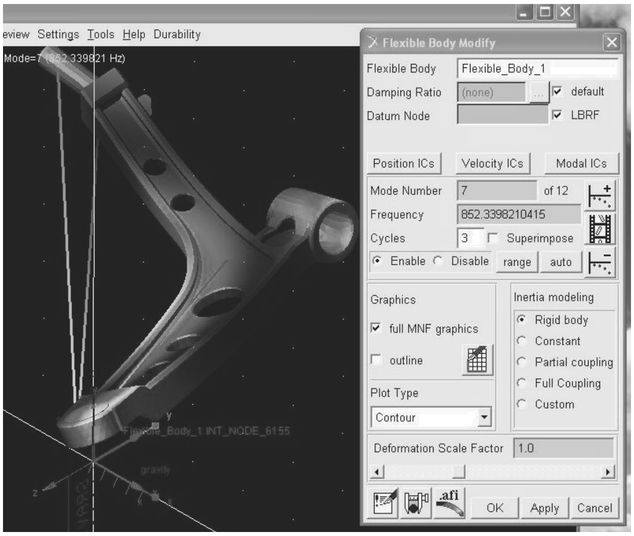


```
   7 : 1.92802001513735e+004  6.98837016084239e+002
   8 : 3.60017191185929e+004  9.54952458797601e+002
   9 : 7.12205933454689e+004  1.34314507941916e+003
  10 : 2.04360079342940e+005  2.27519250131405e+003
  11 : 2.54031500989646e+005  2.53666968497611e+003
  12 : 3.34941582478733e+005  2.91275975613242e+003

  Appling Cram-Schmidt to eigenvectors

Orthogonal mode file: D:\DOCUME-1\lukasz\USTAWI-1\Temp\mnf_3
  8%,     0 seconds left of     0 estimated total          16%,


Creating a Modal Neutral File with the following information:

                  Nodal Coords Yes
                 Element Faces Yes
                   Eigenvalues Yes
                   Mode Shapes Yes
        Global Mass Properties Yes
                  Nodal Masses Yes
                Nodal Inertias No
         Generalized Stiffness Yes
              Generalized Mass Yes
           Generalized Damping No
           Mode Transformation Yes
                  Stress Modes No
               Interface Nodes Yes
            Inertia Invariants No
                 Modal Preload No
                   Modal Loads No
                  Strain Modes No

Node info:
   Count: 6155

Global body properties:
Mass          : 2.820074

Center of Mass: -109.397955 201.192294 12.359780
Inertia Tensor: 142481.211377 -81367.387281 -3506.413569
                -81367.387281 59855.696963 6498.241215
                -3506.413569 6498.241215 201162.829993

Eigenvalue info:
   Modes: 12

Trans Mode info:
   Modes: 12
   Nodes: 6155
```

Fig. 9. Eigenvectors for a steel suspension arm

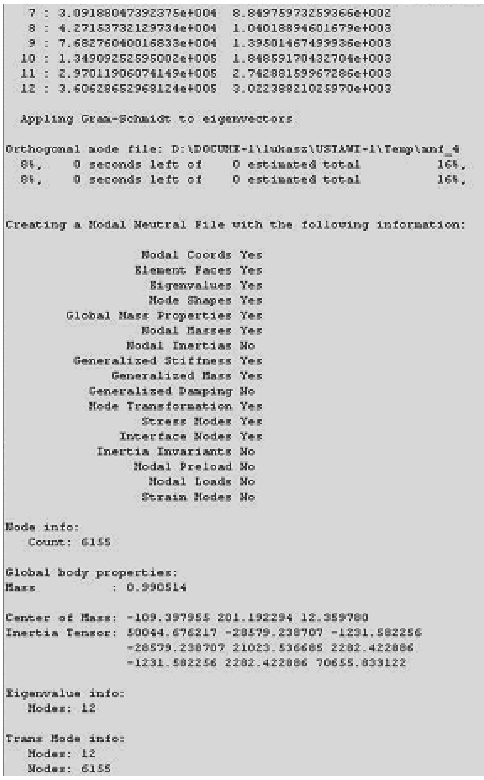
The next step in the study was to establish eigenvectors (free vibration frequency) for the flexible suspension arm model

(Figs. 9 and 10). Establishing all vectors in a discrete system (FEM model) is very time and memory consuming. In most cases of engineering calculations, several to several dozen proper pairs having the most relevant forms matter in practical terms.



Flexible Body: Flexible_Body_1
Damping Ratio: (none) ☑ default
Datum Node: ☑ LBRF
Mode Number: 7 of 12
Frequency: 852.3398210415
Cycles: 3 ☐ Superimpose
● Enable ○ Disable
Graphics: ☑ full MNF graphics ☐ outline
Plot Type: Contour
Inertia modeling: ● Rigid body ○ Constant ○ Partial coupling ○ Full Coupling ○ Custom
Deformation Scale Factor: 1.0

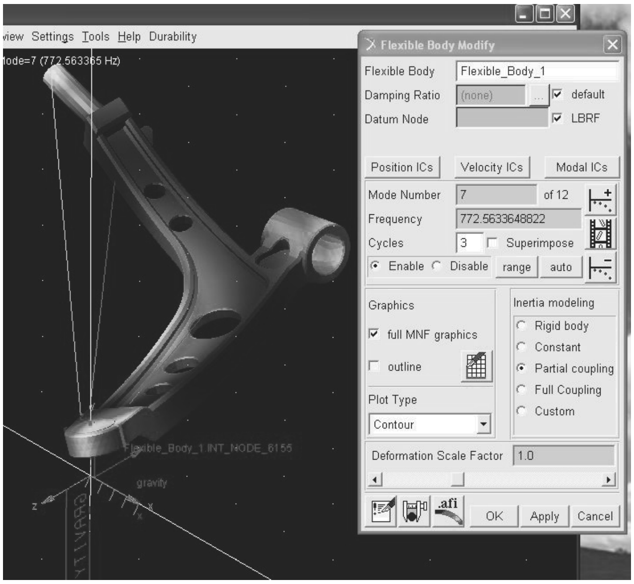
Fig. 10. Form of vibrations for mode no. 7 – steel suspension arm



```
   7 : 3.09188047392375e+004  8.84975973259366e+002
   8 : 4.27153732129734e+004  1.04018894601679e+003
   9 : 7.68276040016833e+004  1.39501467499936e+003
  10 : 1.34909252595002e+005  1.84859170432704e+003
  11 : 2.97011906074149e+005  2.74288159967286e+003
  12 : 3.60628652968124e+005  3.02238821025970e+003

  Appling Gram-Schmidt to eigenvectors

Orthogonal mode file: D:\DOCUME~1\lukasz\USTAWI~1\Temp\anf_4
  8%,    0 seconds left of    0 estimated total          16%,
  8%,    0 seconds left of    0 estimated total          16%,


Creating a Modal Neutral File with the following information:

                  Modal Coords Yes
                 Element Faces Yes
                   Eigenvalues Yes
                   Mode Shapes Yes
        Global Mass Properties Yes
                  Nodal Masses Yes
                Nodal Inertias No
         Generalized Stiffness Yes
              Generalized Mass Yes
           Generalized Damping No
           Mode Transformation Yes
                  Stress Modes Yes
               Interface Nodes Yes
            Inertia Invariants No
                 Modal Preload No
                   Modal Loads No
                  Strain Modes No

Node info:
   Count: 6155

Global body properties:
Mass          : 0.990514

Center of Mass: -109.397955 201.192294 12.359780
Inertia Tensor: 50044.676217 -28579.238707 -1231.582256
                -28579.238707 21023.536685 2282.422886
                -1231.582256 2282.422886 70655.833122

Eigenvalue info:
   Modes: 12

Trans Mode info:
   Modes: 12
   Nodes: 6155
```

Fig. 11. Eigenvectors for an aluminium suspension arm

The procedure was repeated for the model made of aluminium, the results of which have been provided in Figs. 11 and 12.



Flexible Body: Flexible_Body_1
Damping Ratio: (none) ☑ default
Datum Node: ☑ LBRF
Mode Number: 7 of 12
Frequency: 772.5633648822
Cycles: 3 ☐ Superimpose
● Enable ○ Disable
Graphics: ☑ full MNF graphics ☐ outline
Plot Type: Contour
Inertia modeling: ○ Rigid body ○ Constant ● Partial coupling ○ Full Coupling ○ Custom
Deformation Scale Factor: 1.0

Fig. 12. Form of vibrations for mode no. 7 – aluminium suspension arm

5. Complete car model

The foregoing procedure pertaining to having taken the suspension arm model into consideration as a flexible body is assumed to apply the said model in a complex suspension system of a complete car created in the Adams/Car environment. The car model to be used in future studies has been depicted in Fig. 13.

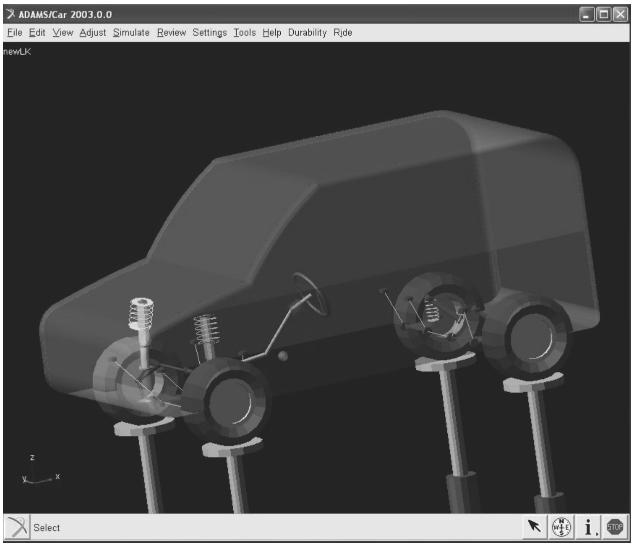


Fig. 13. Complete car model

6. Conclusions

The study results discussed are related to a numerical experiment. The model in question requires experimental verification for the modal frequencies established (fine-tuning, e.g. by changing physical properties).

After the tuning, the discrete model of a car suspension arm will be used as a flexible element of a complex car suspension system (MBS). The complete car model prepared enables examinations in the Adams/Car environment while defining any chosen input functions (e.g. those caused by the road profile). One can additionally conduct strength related tests in the Adams/Durability module (visualisation of stresses, positioning of hot spots). In conclusion, the results discussed in this paper are only applicable to a small part of works related to the studies of dynamics of automotive vehicle suspension systems using the Adams software.

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