Prediction of fatigue life of suspension parts of the semi-trailer in the early stages of design

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Abstract. Cargo delivery by trucks is a main method of transportation of goods to the cities and other places. Many goods are transported by articulated lorries. Thus, improving the design methods of the articulated lorries is relevant. Trailer suspension is the object under study. A fatigue life prediction of the trailer suspension components is an urgent task at the early stage of design concept development. The formation principles of the MBD model are essential in obtaining best results. In this paper two types of models are considered: containing only the rigid bodies; containing the flexible bodies. Research objective: the investigation of the effect of the load distribution that was obtained using different MBD models on the durability of suspension parts. A comparison of the results obtained using the different suspension models was performed. The research has shown that loads are reduced using the flexible bodies in the MBD model. Using flexible bodies permits to specify the results of the durability analysis.

1. Introduction
Cargo delivery by trucks is a main method of transportation of goods to the cities and other places. Many goods are transported by articulated lorries. Thus, improving the design methods of articulated lorries is relevant\cite{1-5}.

It's known that mass reduction of the unspring parts significantly improves the driving performances such as the ride comfort, average speed, fuel efficiency \cite{6-15}.

The durability of the suspension parts refers to the fatigue initiation life defined as the number of cycles to a specific crack length of the component under cyclic loads. Often the S-N curve of metal is described by a power function (Basquin's equation) which means a highly nonlinear dependence of the number of cycles on stress. The refinement of dynamic models by using the flexible parts (suspension elements and a bearing system) can significantly affect the load distribution in the system, which may affect the results of the fatigue life \cite{16-23}.

Research objective: estimation of the influence of the flexible bodies on loads which were obtained using the dynamic model of the semi-trailers on the durability of the suspension parts.

In this paper a dynamic model of the articulated lorries is developed which takes into account the flexible suspension parts, nonlinear stiffness of the suspension mounts, the flexible axils, frame and tank. The load calculation is performed using the MBD program. The MBD model was performed in AltairHyperWorks software (Motion solve). The movement on the different rigid uneven roads was simulated.
Finite-element (FE) models and the stress-strain analysis are performed in Altair HyperWorks software. FE models were created using HyperMesh, for the definition of stress OptiStruct was used. Fatigue life analysis was performed in CodeDesignLife software.

2. Mathematical model of the articulated lorry
Dynamic model of the articulated lorry is shown in . This model was performed in the MBD program. Components of the mathematical model of the vehicle are shown in Figure 2. Mathematical model of the articulated lorry includes: models of the truck, tank, suspension and wheels.

In the model, the following assumptions are made:
– parts of the truck are rigid;
– articulated lorry is moving at a constant speed (60kph);
– for gross vehicle weight calculations are performed;
– joints haven’t internal friction;
– the liquid occupies the entire volume of the tank;
– center of gravity of the trailer is constant;
– trailer suspension is equalizing;
– suspension characteristic is nonlinear;
– deflection of the tire is taken into account. Loads are applied to the wheel axle.

Road irregularities are defined by its spectral density \( D_q = 5.33 \, \text{cm}^2 \). RMS height of the irregularities are \( C = 2.3 \, \text{cm} \), coefficients \( \alpha = 0.15 \, 1/\text{m} \) and \( \beta = 0 \). The road profile is taking into account the tire enveloping properties [24].

![Figure 1. MDB model of the articulated lorry with flexible bodies](image-url)
Figure 2. General elements of the mathematical model of the articulated lorry

**Vehicle specifications:**

| Specification           | Value             |
|-------------------------|-------------------|
| Gross vehicle weight    | 54400 kg          |

**Gross vehicle weight distribution:**

| Component                          | Weight          |
|------------------------------------|-----------------|
| Front suspension of the truck      | 6400 kg         |
| Rear suspension of the truck       | 21000 kg        |
| Suspension of the semi-trailer     | 27000 kg        |
| Cargo weight                       | 38000 kg        |
| Tire of the truck                  | KAMA 315/80 R22.5 NR-201 |
| Tire of the semi-trailer           | KAMA 385/65 R22.5 NT-201 160K |

**Semi-trailer suspension:**

- **Type:** Dependent suspension
- **Spring type:** Air spring is 2927V
- **Damper:** Shock absorber is Wabco 4386
The equalizing beam suspension was created. The suspension model was implemented as an external DLL-file. The file implements an algorithm for calculating the force that occurs on each air spring. The magnitude of a force depends on the volume variation of all air springs of the semi-trailer. The geometric dimensions of the 2927V air spring are used. Additional volumes (receivers) and control mechanisms are not taken into account. The model transfers equal forces to each air spring. Similarly, the rear suspension of the truck was modeled. The front suspension of a truck is spring.

The mathematic model of each suspension of the semi-trailer includes the shock absorbers 1, air springs 2, axil 3 and arms 4. The arms are fixedly connected to the axis. Also, the each suspension arms are connected to the frame bracket 6 via a mount 7. Tension springs with variable stiffness were used to limit the wheel rebound. If critical displacement is not achieved then the stiffness of the spring is about zero. If critical displacement is achieved then the stiffness is high. The hub bearings are modeled via the revolute joint.

To identify the effect of the compliance of the suspension parts on load distribution in the joints the flexible bodies are used. Flexible bodies are defined by Craig-Bampton method, based on specially developed finite element models of the suspension parts.

![Figure 3. The equalizing beam suspension of the semi-trailer](image-url)

To investigate the motion simulation along an uneven road with a distance of about 10 km was performed. Comparisons of known mathematical models of the interaction of wheels with an uneven rigid surface were made [25-28]. To simulate the interaction of the wheels with the uneven road MF-Tire model was chosen, which is described in detail in the paper [29].
3. Estimation of the results

As a result of modeling the movement of the articulated lorry on an uneven rigid road, joint loads were obtained. As an example, vertical force spectrum in the hub bearing of the left front wheel for the flexible and rigid bodies is shown in Figure 5. Results processing was performed. Diagrams of magnitude of loads from their frequency of appearance were obtained. For clarity purposes, results are presented in graph form (Figure 6).

![Diagram of suspension components](image)

**Figure 4.** Components of the mathematical model of the suspension
1 – shock absorber; 2 – air spring; 3 – axil; 4 – arm; 5 – cable (limiter);
6 – bracket; 7 – mount; 8 – brake;

![Graph showing vertical force](image)

**Figure 5.** Vertical force in the bearing of the front left wheel hub of the semi-trailer trolley for models with the rigid and flexible bodies
Based on the results of the research, the following conclusions were made:

1. The RMS vertical reaction force of the hub bearing decreases by 5.5% when using flexible bodies. Similar for other joints.
2. Maximum loads decrease by 10.9%.
3. Frequency of appearance of large loads is less. As an example, for a load whose magnitude is 90kN, frequency of appearance is 10 times less using flexible bodies.

4. **FE model of suspension**

   FE model is shown in . Suspension arms which are made of metal sheets were modeled via shell elements (QUAD4). Arms levees were modeled via solid elements (HEX8).

   Loads application nodes is shown in: 1* - load node of the air spring; 2* - load node of the brake; 3* - load node of the frame bracket; 4* - load node of the shock absorber; 5* - load node of the hub bearing; 6* - load node of the midpoint axil.

   The loads acting on the bearing from the hub are transferred to the outer ring through RBE2. Contact interaction of the bearing and the hub was taken into account. The pretension load of the bearing was modeled via negative clearance between nut and the end face of the bearing. The pretension load is 90kN. FE model of the bearing is shown in Figure 9.

   Outer and inner bearing rings were modeled via solid elements. Contact interaction of rings with rollers was modeled by RBE2 elements, its dependent nodes located along the contact line. RBE2 elements of the outer and inner bearing rings is connected through independent nodes by rod elements ROD.

**Figure 6.** Comparison of vertical force in the bearing of the front left wheel hub
Figure 7. FE model of the suspense on: 1 – arm; 2 – pin; 3 – bearing; 4 – nut; 5 – brake flange; 6 – axil; 7 – bracket

Figure 8. Load nodes
5. Fatigue life analysis
Consider the effect of the loads that were obtained using rigid bodies or flexible bodies for the MBD model. Fatigue life analysis of suspension parts was performed. In this paper, estimation of durability of the seam-welded joint is not considered. For fatigue life analysis, stress-based approach was used. This is sufficiently for a quantitative and qualitative comparison of the results. Mean stress effect was taken into account according to the Goodman’s model.

Calculation results are presented in Figures (rigid bodies) and (flexible bodies). The calculation results show that the loads that are obtained using different models (rigid or flexible bodies) significantly affect the calculation results of the fatigue life prediction. In this example, the number of cycles the minimum number of cycles differs almost 3 times (10239 cycles for rigid bodies and 32698 cycles for flexible bodies).

Figure 9. FE model of bearing

Figure 10. – Calculation results for rigid bodies loads
6. Conclusions
1. The RMS vertical reaction force of the hub bearing decreases by 5.5% when using flexible bodies. Similar for other joints.
2. Maximum loads decrease by 10.9%.
3. Frequency of appearance of large loads is less.
4. The number of cycles the minimum number of cycles differs almost 3 times: 10239 cycles for rigid bodies and 32698 cycles for flexible bodies.

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