Elastic rail clip design development, based on virtual prototyping

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Abstract. Virtual prototyping technology is a powerful tool when exact design solution is needed, corresponding to various and sometimes controversial requirements. It is used widely for design improvement/optimisation (topology, shape, parametric), based on engineering analysis through numerical techniques (as Finite Element Method) that enables prompt and accurate solutions. Design development approach based on this technology becomes standard for many industries, including railway transport. Presented study is based on an industrial project for design development of elastic rail clip. It is entirely based on virtual prototyping to obtain adequate design solution. Design is required to achieve certain clip rigidity, at certain level of safety (mechanical stress), for certain design space. This is a typical task for design optimisation techniques and performed simulations include 3 design concepts, 11 design variants and more than 2400 parametric configurations to obtain 4 allowable design solutions. The study is a good presentation of virtual prototyping application for industrial purposes.

1. Introduction

Virtual engineering is based on virtual prototyping technology, which is a mean, method, and technology that allows the product to be developed entirely in virtual environment, including virtually simulating its behaviour during operation, and simulating processes and operations for its production (Figure 1). [1]

Virtual prototyping allows product examination before creating real physical objects (prototypes) or optimizing different parameters in parallel with physical prototyping. At the development stage, the engineer uses literature, similar designs, rough formulas for evaluation, and his personal experience. This leads to adequate solutions, but very rarely they are optimal. In order to reach an optimal solution, it is possible to use iterative-intuitive optimization, which modifies a given design with the help of CAE software. This is labor-intensive, slow and not always cost-effective. In these cases, other optimization methods must be used - parametric, topological or form optimization.[2]

The spring clip is an element of the rail track accessories intended for elastic fastening of the rail to the base. The most important requirement expected from the spring clip is to be in the constant contact with the rail in any condition which might occur during the exploitation [3]. They have to withstand the force created when a train runs over the railway, i.e. must provide enough fastening strength [4].

Their stiffness of a fastening system is one of the most important characteristics that directly impacts the fastening system’s long-term performance under repeated axle loading. Stiffness closely relates to the degree of wear fastening system components experience, and the resulting life of the system. The stiffness of each component determines how much the rail is allowed to move within the
rail seat. For the purpose of studying fastening system component behavior, it is possible to isolate a force vector and analyze how each fastening system component will perform under a discrete loading event [5, 7].

Clamping forces can be developed by either bolting or screwing an elastic clip into a cast-in shoulder. Alternatively, a clip can be driven into a cast-in shoulder, which forces the clip to hold the base of rail with the prescribed clamping force. These two systems could be referred as “bolt or screwed clip systems” (Figure 2) and “driven clip systems” (Figure 3). These systems should provide functions of fixation long-welded tracks at the temperature influence on the rails and of the primary amortization for dynamic interaction between a track and a rolling stock. [6, 7]

In the fastener industry, the development of railway fasteners is going to be high added value oriented, in response to the advancement of the railway industry and the construction of the high speed rails, metros, and light rails. [4].

This research concerns development of a NEW design of rail spring clip, using all available virtual prototyping techniques. This allows to explore numerous variants without expensive and time-consuming physical prototyping and testing, in parallel with reviewing in detail the force-deflection behavior of the structure, aiming to accelerate reaching of best variant.

The definition of design variants of an elastic element (spring) must apply to two basic criteria:
- Stiffness: maximum spring displacement of 8mm is required with an applied force of 11kN (twice, at the two symmetrical ends of the spring);
- Strength: The stress at maximum load should not exceed 650MPa.

2. Approach to examined problem
Nowadays more and more companies are introducing and using modern computing methods to speed up the process of developing and improving the quality of their products. The use of numerical optimization
methods can be very successfully applied to obtain "systematic and workable" solutions. The solutions generated automatically give the engineers new, unfamiliar or difficult to predict proposals for solutions, while at the same time reaching the "optimal design". Essentially this is the most effective workflow possible.

Main idea of presented process is to apply required load of 11kN and to calculate displacement (target value of 8mm) and stresses (tension and compression). The successive candidate must have 8mm displacement and stresses below limit of 650MPa.

Presented approach is based on a combination of conceptual variations with parametric optimization procedures. Three main concepts are examined – “bracket”, “meander” and “spring” concepts. Each concept has 3 to 4 sub-concepts, and parametric optimization procedure is run for each sub-concept variant. A general scheme is presented on Figure 4. Final evaluation is performed by comparing BEST parametric variants for each sub-concepts by its stresses.

![Figure 4. Examined design concepts and their variants.](image)

3. Simulation models
All project calculations are performed using Finite Element Models of concepts, used further for engineering analyses. Built FE models are shown on Figure 5.

- “Bracket” design concept, having sub-concept variants:
  - Bracket with constant circular cross section – BCC
  - Bracket with constant rectangular cross section – BCR
  - Bracket with variable rectangular cross section – BVR
  - Bracket with trapezoidal cross section – BT
- “Meander” design concept, having sub-concept variants:
  - Flat vertical meander spring with 1.5 turns – MH1.5
  - Flat vertical meander spring with 2.5 turns – MH2.5
  - Flat horizontal meander spring – MV
- “Spring” design concept, having sub-concept variants:
  - Spring with wire diameter D=15mm – S15
  - Spring with wire diameter D=20mm – S20
  - Spring with wire diameter D=25mm – S25
  - Spring with wire diameter D=30mm – S30
It is important to note that all these models use symmetry condition (half or quarter model), that is predefined by their geometry and load symmetry.

Applied boundary conditions correspond to the initially defined specification. Samples for applied boundary conditions are shown for each concept on Figure 6 below.

Virtual prototyping using FEM software has performed, through parametric optimization (Design of Experiments – DoE) for all different concepts, with variants in some cases reaching up to 1000 iterations of predefined design parameters.

Figure 5. FEM of all examined design sub-concepts: (a) – BCC; (b) – BCR; (c) – BVR; (d) – BT; (e) – MH1.5; (f) – MH2.5; (g) – MV; (h) – S20; (i) – S25; (j) – S30; (k) – S15.
Figure 6. Applied boundary conditions for samples of examined design concepts: (a) bracket type design concepts, (b) meander type design concepts and (c) spring type design concepts.

The specifics for each of the three concepts are briefly listed below:

a) **“Bracket” design concept**: the set boundary conditions are considering the symmetricity of the design and loading in two directions, which allows examining a $\frac{1}{4}$ of the geometric model. 100 variants with variable geometric parameter such as different cross section dimensions and overall profiles and radiuses have been analysed.

b) **“Meander” design concept**: it has been developed in vertical position that aims examination of the performance of such solution. Its model is symmetrical in one direction which allows simulating a $\frac{1}{2}$ geometric model and also the applied boundary conditions are $\frac{1}{2}$ of the original ones.

c) **“Spring” design concept**: it has a tension arm which is directing the applied forces against the support and eliminating the torsion of the whole construction. The model is symmetrical in one direction which allows simulating a $\frac{1}{2}$ geometric model and also the applied boundary conditions are $\frac{1}{2}$ of the original ones.

4. Analysis results and comments

All examined parametric variants for the three concepts and 11 (in total) sub-concepts exceeds 2400. Thus, it is not suitable to present all results and only a successful variant for each of the three concepts is presented below.

a) **“Bracket” type design**: A suitable solution having the desired strength and rigidity set by the technical assignment has not been found. The results from one of the closest matching variants are demonstrated on Figure 7. Main problem with this design concept is high level of stresses due to decreased quantity of material used for it.

b) **“Meander” design concept**: Four variants have been analysed, and a solution that having the desired strength and rigidity has been found. This variant has constant cross section of the bent bracket with dimensions 15mm height and thickness of 45mm. The overall dimensions of the
spring are 180mm in length, and 80mm in width. The results from the successful variant are shown on Figure 8.

c) **“Spring” design concept**: Simulation results for the most successive of all examined variants are presented on Figure 8. The maximal stresses are close to the limit ones. With compressional stresses going up to 1000 MPa and tensional – up to 560 MPa.

![Figure 7. Maximal equivalent stress distribution for “Bracket” type design, MPa.](image)

Figure 8. Maximal equivalent stress distributions, MPa: (a) “meander” type design and (b) “Spring” type design.

5. Results analysis

Results analysis is based on a comparison, performed using bar graph showing the maximal compressional and tensional stresses for successive representatives for each of examined sub-concepts. It is shown on Figure 9. The results of the performed analyses and parametric optimization are leading to the following summary:

- “Bracket” design concept does not give successive solution and it is not usable for further investigations;
- “Meander” design concept has successive solutions for each of its 3 sub-concepts and is possible to be developed further. Major concerns about this design concept is technological difficulties.
“Spring” design concept is probably the best solution. Sub-concept with wire of 25mm diameter shows relatively low stresses, reaching requested displacements.

General conclusion is to be formed after detailed technological analysis of “meander” and “spring” concepts candidate variants.

6. Conclusion
Presented study demonstrates a typical task for design optimization techniques and performed simulations using virtual prototyping. A combined (shape and parametric optimization) approach is used to evaluate 3 design concepts, their 11 sub-concepts and more than 2400 parametric configurations to obtain 4 allowable design solutions. Final decision is left to technological analysis. The study is a good presentation of virtual prototyping application for industrial purposes, where no physical prototype is built before reaching final successive design concept, decreasing lead time for product development and avoiding physical prototyping and testing expenses at early concept development stage.

Acknowledgments
This research study is performed by the support of project DN-17/15 “VIrtual and experimental VAlidation of acoustic emissions of mobile rolling-stock for ECOlogical transport” of National Science Fund, Ministry of Education and Science, Bulgaria.

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