Dragan Petrović
Assistant Professor

Zlatan Šoškić
Assistant Professor

Nebojša Bogojević
Teaching Assistant

Ranko Rakanović
Professor

Faculty of Mechanical Engineering
University of Kragujevac

Work Regime of DDam Wagon Parabolic Springs

This paper presents results of statistical analysis of stresses of parabolic springs of car transport wagon DDam in exploitation conditions. Contrary to common conviction, it turns out that work regime of car transport wagons springs may be considered as light.

Keywords: *Spring, Stress, Freight wagon.*

1. INTRODUCTION

Springs are essential element of railway vehicles suspension that surpasses deformation in its work. Process of designing or selection of appropriate springs includes satisfaction of various exploitation requests considering static and dynamic loads, geometry and quality of track etc. Differences between mean values of loads of different classes of freight wagons are large, so that true picture of work regime of freight wagon springs may be obtained only through experimental analysis.

Usual manner for experimental analysis of spring behavior includes development and application of test stands, where programmed forces and regimes are applied to springs [1, 2]. Although capable of estimating quality of springs, such methods do not offer insight into their work regime when mounted on specific railway vehicle.

Common practice considers work regime of freight wagon springs as medium or hard [3], leading to design and application of springs that have large stiffness, which in some cases leads to deterioration of wagon's quality of running.

Figure 1. Wagon DDam

For this reason, Railway Vehicles Center of Faculty of Mechanical Engineering, Kraljevo decided to perform analysis of work regime of springs of car transporter DDam that is widely used by Yugoslav Railway.

DDam is three-axes, two-part, double-deck wagon for transport of automobiles (Fig. 1). Its dead weight is 27 t, with carrying capacity of 20 t, designed for speeds up to 120 km/h in S and SS regime. It is equipped with parabolic springs of German manufacturer Langen & Sondermann, made from 50CrV4 steel (according to DIN 17221-17222) (Fig. 2).

Figure 2. Spring at middle axle of DDam wagon

Force-displacement dependence of the spring is provided by manufacturer and shown in Fig.3. It also presents static stresses for empty and fully loaded wagon, as well as maximal spring stress.

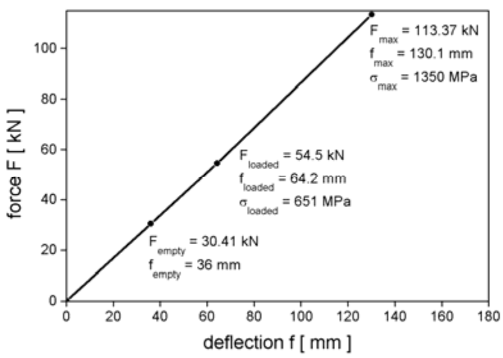

Figure 3. Manufacturer static characteristic of investigated spring

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Correspondence to: Dragan Petrović
Faculty of Mechanical Engineering, University of Kragujevac,
Dositejeva 19, 36000 Kraljevo, Serbia and Montenegro
E-mail: petrovic.d@maskv.edu.yu

2. EXPERIMENT

2.1 Measurement methodology

In order to obtain estimation of work regime, spring stresses were measured at both springs at middle axle. This choice was made because previous exploitation showed that middle axes springs had most cracks.

At each spring, stresses were measured in longitudinal (x) and transversal (y) direction by application of standard tensometric techniques, as it is shown in Fig. 4. Being that middle axle spring joins two wagon units, transversal strain gauge was put to register stresses that may arise as a consequence of change of mutual position of units during wagon motion through curves. Besides stresses, deflection of the same springs was measured.

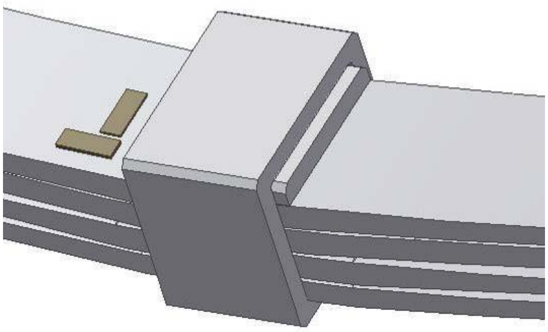

Figure 4. Strain gauges positions

Experimental data were acquired during test rides for investigation of dynamic behavior of the wagon according UIC-518. Besides, data were acquired during preparation rides between UIC-518 track sections. Preparation rides included tracks with low quality of tracks, tracks with geometry not covered by UIC-518, rides during wet weather and so on. Being that UIC-518 requests both rides with empty and loaded vehicle, acquired data represent valid basis for investigation of springs under exploitation conditions.

The data were also acquired during wagon loading in order to investigate static state of spring. On this occasion wagon axle load was measured in "Bratstvo" factory, DDam wagon manufacturer.

Measurement data were sampled using HBM MGCPlus data acquisition system with 200 Hz acquisition rate and low-pass filter with cut-off frequency 40 Hz applied. Total amount of acquired dataset had duration of more than 4 hours describing length of approximately 290 km of ride.

Stress was measured by HBM 10/120LY11 strain gauges with resistance (120±0.35%) Ω and gauge factor 2.04±1%. Each strain gauge was part of separate Wheatstone bridge with three compensation strain gauges for the sake of temperature compensation and cable length compensation. Output voltage was measured with accuracy better than 0.1%. Considering Wheatstone bridge equation and mentioned data stress measurement instrumentation error can be estimated to be less than 2%.

Deflection was measured by HBM WA 100 displacement transducer (Fig. 5) that has nominal instrumental measurement error less than 1%.

2.1 Static measurements

As previously mentioned, static measurements were performed during wagon loading. Spring stresses caused by structure (empty wagon) weight were adopted as zero level.

Measured wagon axle load data are presented in Tabele1.

Table 1.

Axle load [kN]	I axle	II axle	III axle
Empty	96.4	66.5	98.6
Loaded	165	138	164

Mean static spring stress of middle axle springs of loaded wagon was measured to be $\sigma_{st} = 788$ MPa .

Fiure 5. Mounting of displacement sensor

2.2 Test rides

Test rides with empty and loaded wagon were performed on Serbian Railways commercial railroads sections Šid-Belgrade and Jajinci – Ćuprija.

Test tracks for spring work regime investigation were classified similar to UIC-518 classification to 6 zones (UIC-518 defines four of them):

Z1 – tangent track zone

Z2 – large radius curve zone ($R \geq 2500$ m)

Z3 – small radius curve zone (400 m < $R \leq$ 600 m)

Z4 – very small radius curve zone (250 m ≤ $R \leq$ 400 m)

Z5 – point switch and crossing zones

Z6 – medium radius curve zone (600 m ≤ $R \leq$ 1500 m)

Running speeds at each zone tracks is presented in Table 2.

Table 2.

Zones	Z1, Z2	Z3, Z4, Z6	Z5
Speed [km/h]	130	80÷120	50÷130

Test tracks were laid at 1/20. Track geometry was determined by measurement measuring vehicle of and data were processed by AP00 software of Serbian Railways based on Yugoslav Railways Instruction 339 that considers common criteria for track quality control.

Track quality limits QN1 and QN2 for vertical alignment, horizontal alignment and cant deficiency defined in UIC-518 are applied in order to estimate if the selected tracks can represent exploitation conditions on Serbian Railway railroads. As an illustration, track geometry data describing section Jajinci-Mala Krsna (having the lowest quality and not suitable for testing according UIC-518) are presented in Fig. 6.

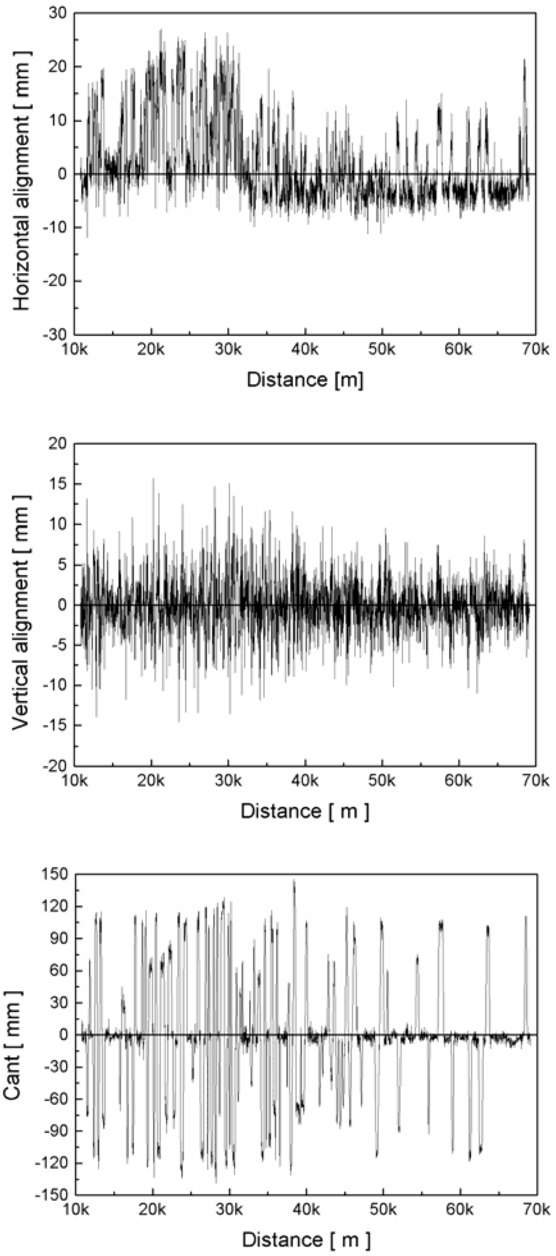

Figure 6. Track geometry data on section Jajinci-M. Krsna

3. ANALYSIS

Static measurement data were compared to manufacturer data to determine if mounting stress exists. Taking into consideration measured axle loads and the fact that DDam axle weight (including spring weight) is 12.5 kN, static force acting on each middle axis spring of loaded wagon is 63 kN. According to manufacturer's force-displacement diagram, spring stress of empty wagon is 325 MPa, and spring stress of loaded wagon is 754 MPa. Being that measured spring stress of loaded wagon is 788 MPa, it can be concluded that remarkable mounting stresses do not exist.

Test rides data are processed according to usual methodology of machine parts work regime analysis [4].

The goal of methodology is formation of ordered set of stress spans that describe state of considered element, in this case the spring. Changes of stress state of element causes fatigue, and therefore crack of spring. The basic hypothesis of the analysis is that the largest influence on fatigue has the magnitude and number of changes, whereas frequency and speed of change do not play significant role, so they are not considered in this analysis.

Fig. 7 [4] presents an example of stochastic change of stresses that is to illustrate concept of quantification of stress changes. The span of i-th stress change (denoted as σ_{ri}) is magnitude of difference between consecutive local minimum and maximum of stress. The spans are classified according to their magnitude, and histogram of spans is made where the width of histogram class is selected to be narrow enough to enable resolution of spans, and wide enough to pertain statistical nature of method.

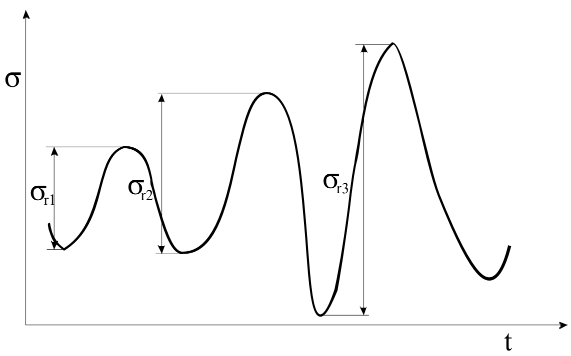

Figure 7. Stress spans

The regime of work is estimated according to overall form of histogram, where key element is relation of the most probable stress span to median of measured stress spans, as it is shown in Fig. 8 [4]. If the most probable stress span is significantly lower than median, the regime is considered as light; if the most probable stress span is close to the median, the regime is considered as medium, and if the most probable stress span is significantly bigger than median, the regime is considered as hard.

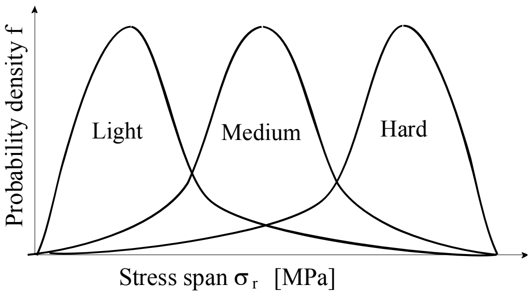

Figure 8. Work regimes

The presented methodology is applied to acquired data. An example of acquired dataset (longitudinal stress of spring on right side of middle axle during 5 seconds of ride) is presented in Fig.9.

It is pretty obvious that the form of real data slightly deviate from the form of theoretically analyzed in Fig. 5. Some stress spans do not represent monotonous functions, but consist of several sub-spans with small falling side. It is, however, our strong conviction that such spans should be treated as one large span for several reasons:

1. It is always possible that such small falls of stress are of artificial nature (due to measurement errors or electric induction influences).
2. Falling side of sub-spans is always much smaller than it is the case with rising side and the overall magnitude of span.
3. Treatment of large span as series of smaller spans would decrease occurrence of large spans and lead to estimation of work regime that might be lighter than real work regime.

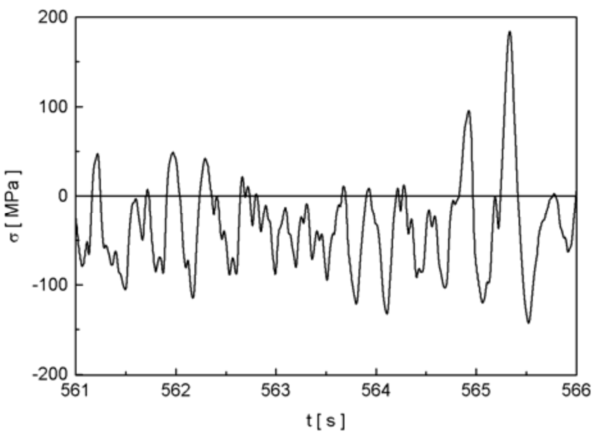

Figure 9. Measured stresses

In order to prevent separation of large spans into smaller spans, a limit on span magnitude is introduced: all sub-spans with falling side magnitude smaller than 10 MPa are considered as part of larger span, as shown in Fig. 10, where two small spans are identified as one span of larger magnitude. As it is aforementioned, it could only lead to harder estimation of work regime.

Based on this approach, histograms of stress spans are made for all measured stresses. During test rides, approximately 50,000 spans were registered. Fig. 11 presents work regime curves for both empty and loaded wagon for longitudinal stress of spring on right side of middle axle, which was the worst case found in analysis.

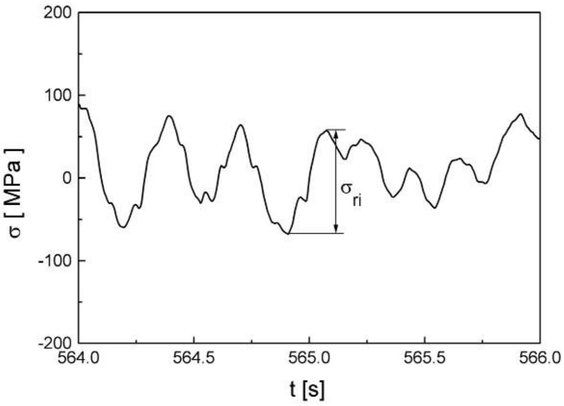

Fig. 10. Separation of large span into sub-spans

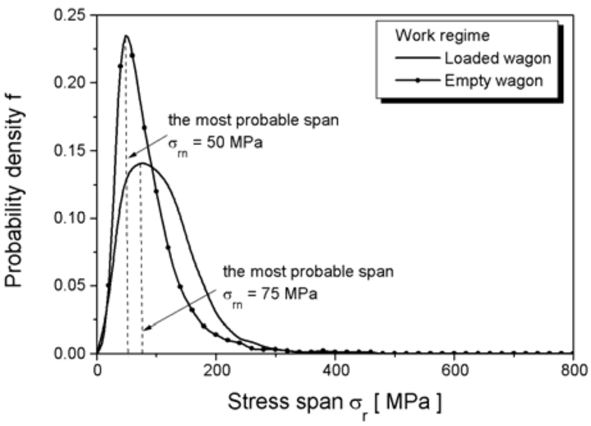

Figure 11. Work regime of investigated spring

Being that the most probable stress spans have values of approximately 50 MPa (empty wagon) and 75 MPa (loaded wagon), while median of measured stress spans has the value of approximately 400 MPa, it is obvious that the work regime of the spring may be considered as light.

4. CONCLUSION

A modified statistical analysis (that could lead only to harder estimation of work regime) of measured stresses of springs in car transport wagon is performed, and stress span histograms were made.

Results show that work regime of springs in DDam wagon may be considered as light, contrary to usual conviction.

We consider the fact to be the consequence of comparatively small load of the wagon; therefore, we consider that such conclusion may be extended to all types of wagons with small loads (whole class of car transport wagons, passenger wagons, etc.).

Such conclusion should have influence on selection of springs for affected types of wagons, as well as on process of wagon spring design. Selection of appropriate springs has large impact on running behavior of vehicle, especially considering quality of ride of railway vehicle.

The prospective work based on these results will include lifetime analysis of springs and determination of safety factor of springs.

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РЕЖИМ РАДА ПАРАБОЛИЧНОГ ГИБЊА ВАГОНА DDam

Драган Петровић, Златан Шошкић, Небојша Богојевић, Ранко Ракановић

У раду су приказани резултати статистичке анализе напонског стања огибљења теретног вагона за превоз аутомобила DDam. Супротно уобичајеним ставовима, испоставља се да се радни режим огибљења читаве класе вагона за превоз аутомобила може окарактерисати као лак.