ADVANCES IN MANUFACTURING SCIENCE AND TECHNOLOGY Vol. 36, No. 2, 2012

MODELING THE EFFECT OF GEOMETRIC ERRORS ON THE STATIC CHARACTERISTICS OF GUIDE RAIL SYSTEMS

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Summary

This paper presents modeling of geometric errors in guide rail systems and how these errors affect their static characteristics. The finite-element method was used for computational analysis, supplemented with technical modeling of butt joints. Different types of geometric errors were assigned to individual elements of guide rail systems, with variations in distributions of clearances and preloads. Selected results of the computational analysis are presented.

Keywords: rolling guideways, geometric errors, stiffness

Modelowanie wpływu błędów geometrii tocznych podzespołów prowadnicowych na ich charakterystyki statyczne

Streszczenie

W artykule przedstawiono sposób modelowania błędów geometrycznych występujących w tocznych podzespołach prowadnicowych. Celem modelowania było ustalenie wpływu tych błędów na charakterystyki statyczne podzespołów. Zastosowana metoda elementów skończonych, wzbogacona o efektywną opcję technicznego modelowania połączeń stykowych, była podstawowym narzędziem analizy obliczeniowej. Przyjęto hipotezę przypisywania poszczególnych rodzajów błędów geometrycznych do odpowiednich elementów konstrukcyjnych podzespołu tocznego – uzmiennione rozkłady wartości luzów lub zacisków wstępnych. Zaprezentowano przykład prowadzonej analizy obliczeniowej.

Słowa kluczowe: prowadnice toczne, błędy geometryczne, sztywność

1. Introduction

The high operational performance of modern technological machines (including cutting machines) is possible through the use of modern efficient construction components. This general rule also applies to guide systems, where traditional sliding joints are increasingly often replaced with rails.

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The basic advantages of these connections are high efficiency, non-occurrence of stick-slip type relaxation oscillations, and accurate positioning of machine units. These characteristics positively influence the technical characteristics of the entire machine. Guide rail systems can be selected during preliminary machine design, and it is easy to predict their behavior during operation.

This paper presents a model – with respect to the static properties – of a guide rail system, i.e. a runner block and a profiled guiding rail. Modeling is based on the finite element method [1], supplemented with the correction of external loads used for contact modeling, developed at the Institute of Mechanical Technology of the West Pomeranian University of Technology [2, 3]. This procedure includes the possibility of modeling geometric errors of a rolling joint in a trolley-rail component. The analytical determination of the static properties includes simulations of errors in the diameters of rolling elements and errors in the geometry of rails and runner blocks.

2. Object of research

The objects of modeling and calculation were single ball rail systems (runner block and rail), manufactured by Mannesmann-Rexroth [4]. The analysis involved a Star ball rail system, (size 25, number 1651 – according to the manufacturer's nomenclature) [4], and recommended preloads 0.02, 0.08 and 0.13 C, where C (dynamic load capacity) means radial loading of constant magnitude and direction which a linear rolling bearing can theoretically endure for a nominal life of 100 km. In this study, C was equal to 22 800 N (Fig. 1).

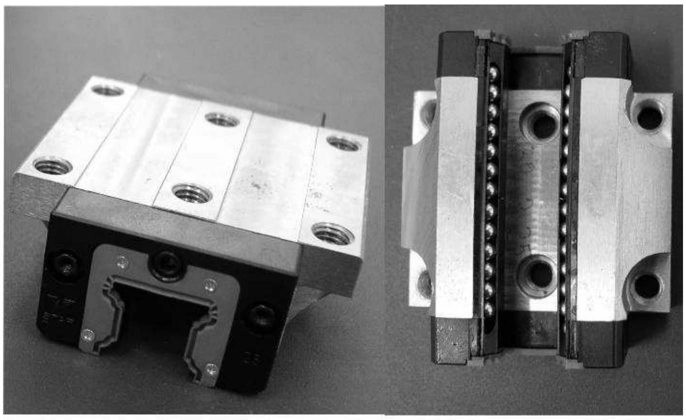

Fig. 1. Studied rail system Mannesmann Rexroth,
catalogue number 1651.25

3. Modeling the rail systems

Modeling procedures consisted of two main stages. The first was the creation of a replacement model of an elementary track-ball-track system (Fig. 2), based on Hertz theory [5]. After building and solving this model, the elastic properties of the system were determined. A prerequisite condition for the proper analysis of these models is the characterization of each single contact element, which reliably describes the properties of the part of the structure that is being replaced by the model. Numerical analyses were carried out using the finite-element method (FEM), using the procedures of contact surface modeling [3, 6].

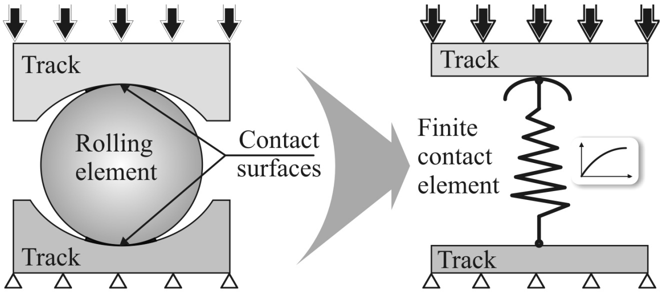

Fig. 2. Modeling of a single rolling segment using a finite contact element

In this proposed method of modeling the rolling segment, a special contact element was introduced. In terms of physical modeling, this element is a one-sided translational spring, fastening the block to the rail at contact points. It has a linear dimension (length), equal to the diameter of the rolling element, and its properties are referred to as the geometric point of contact of a rolling element (a ball) with the track of a movable element (body of the runner block). Contact elements of this type may be used for sub-models – a single pair of a runner block and a rail – and for models of entire joints that use such couples [3, 7, 8].

Reliability in modeling requires that the contact element be supplemented with parameters describing the characteristics of its work. In this study, these parameters were obtained by matching the properties of this element to the description of the rolling segment behavior resulting from Hertz theory. The thus developed element was used in the second stage of modeling to replace elementary track-ball-track segments with single contact elements. It significantly simplified the guide rail system modeling and helped reproduce their complex nature of operation (Fig. 3). Models based on such elements allow the conducting of engineering analyses that provide a variety of information about the behavior of the system, including the loads occurring on the individual rolling elements. This method also enables the modeling of geometric errors of the system, using the method of variation of parameters of distributions of clearances or preloads.

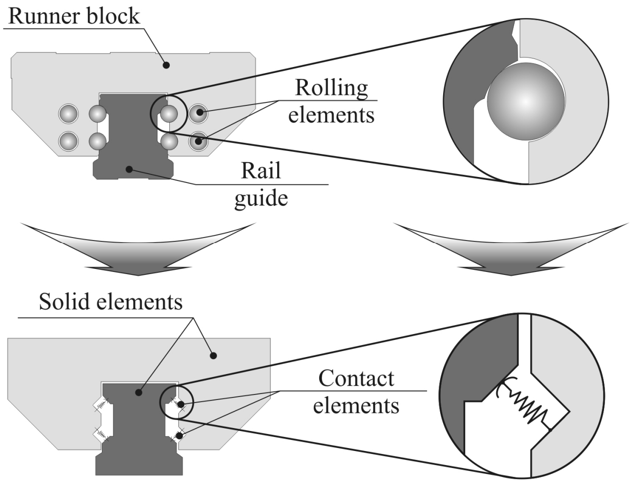

Fig. 3. Modeling of the runner block – rail system

4. Geometric error modeling

4.1 Modeling the errors in the diameters of the rolling elements

Performed as numerical experiments, a series of calculations were made in order to examine the impact of ball diameter errors and geometric errors of the track surfaces on the static characteristics of the runner block-rail system.

The values of the modeled errors were introduced to a set of data that described the model of the system, and the following calculations provided the characteristics of deformations and static stiffness of the system for the external load due to a resulting force in a direction perpendicular to the mounting surface of the runner block.

In the examination of the impact of errors in the ball diameter, it was assumed that the diameters of the balls, 4.75 mm, have a tolerance in an inwards direction with a zero upper and negative lower deviation. Assuming the tolerance T = 0, 2 and 5 μm for all the balls working in the system (4 rows 13 balls each), lower deviations of their diameters were drawn (according to the distribution of equal probability) from the range $\langle -T, 0 \rangle$ (Fig. 4).

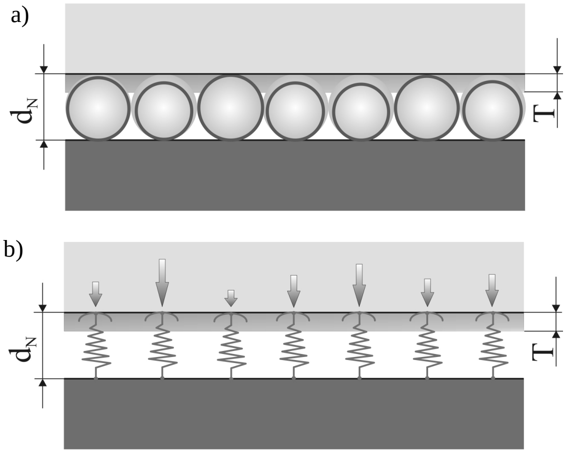

Fig. 4. Scheme of modeling errors in the diameters of the rolling elements in the rail system (a), using contact elements (b)

4.2 Modeling track parallelism errors

Parallelism errors of the contact surfaces were simulated in the same way as errors in the diameter of the rolling elements. A specified error tolerance was also assigned to the contact elements. The values of tolerance T = 0, 2, and 5μm. Lower deviations in their diameters were assumed from the range $\langle -T, 0\rangle$. The parameters reproducing the parallelism error in the contact elements changed linearly along the length of the contact parts of the track. The value of this error was defined as $T = \Delta_1 - \Delta_2$ (Fig. 5).

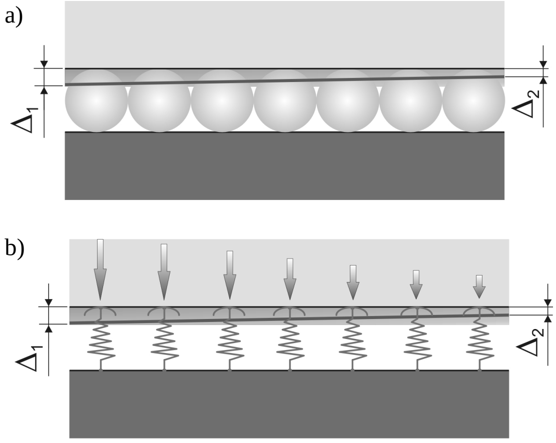

Fig. 5. Diagram of parallelism error modeling in the rail system (a) with the use of contact elements (b)

4.3. Track linearity errors

In track linearity error modeling, it was assumed that within the tolerance range (along the running track) an arc is drawn, defined by three points (beginning, middle, end). The greatest value of deviation occurs at the ends of the contact section arc, and a zero value in the middle of the arc. As previously, the values of tolerance T = 0, 2 and 5 μm for all the contact elements in the system (4 rows 13 pieces each) (Fig. 6).

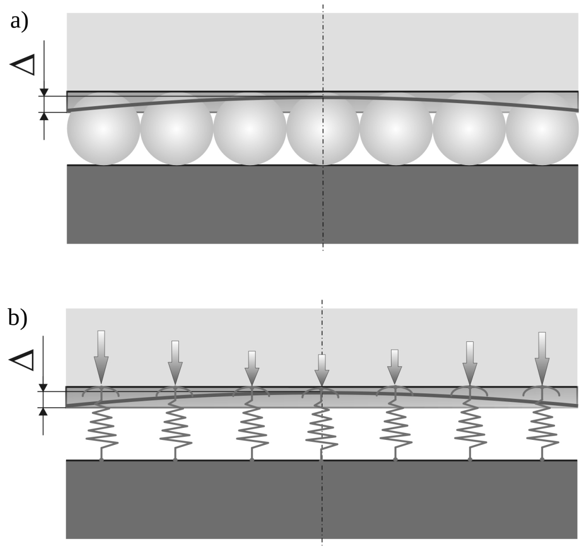

Fig. 6. Diagram of linearity error modeling in the rail system (a) with the use of contact elements (b)

5. The analysis of results

The results of the series of calculations concerning the rail system with the simulated geometric errors and for different values of preloads are presented as graphs in figures 7÷12 (C = 22 800 N – dynamic load capacity, T = 0, 2, 5 μm – tolerance) (Fig. 7).

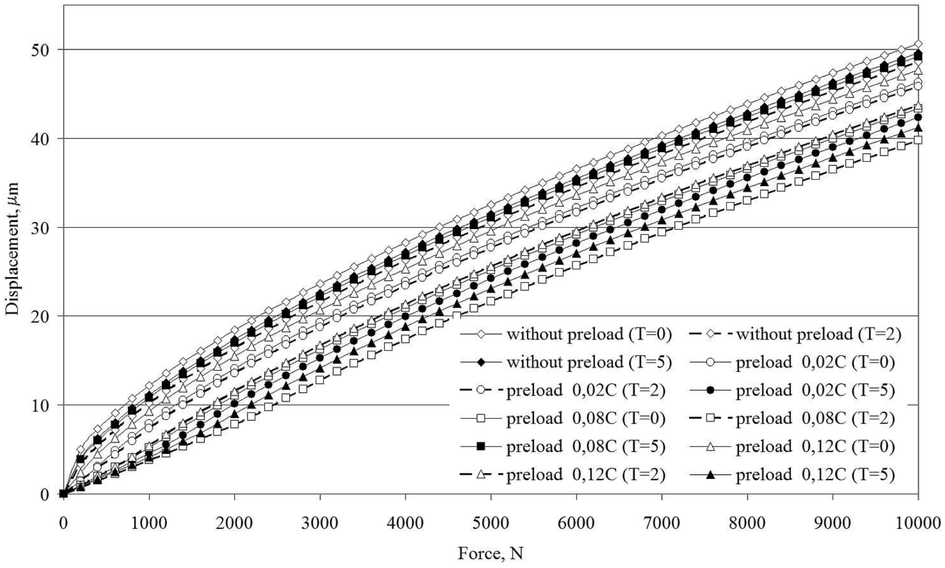

Fig. 7. Characteristics of displacements of the block-rail system, with ball diameter errors, with a preload force perpendicular to the mounting surface of the runner block

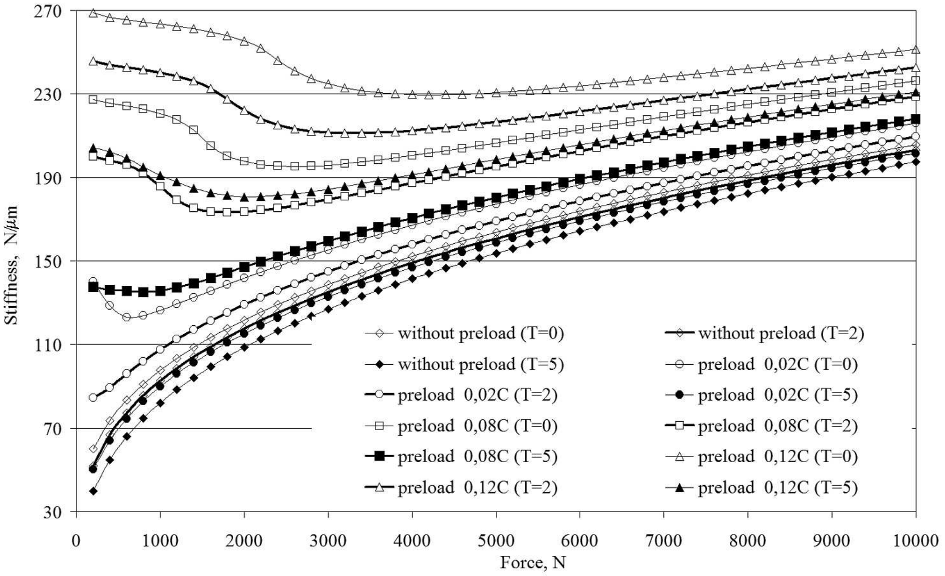

Fig. 8. Characteristics of stiffness of the block-rail system, with ball diameter errors, with a preload force perpendicular to the mounting surface of the runner block

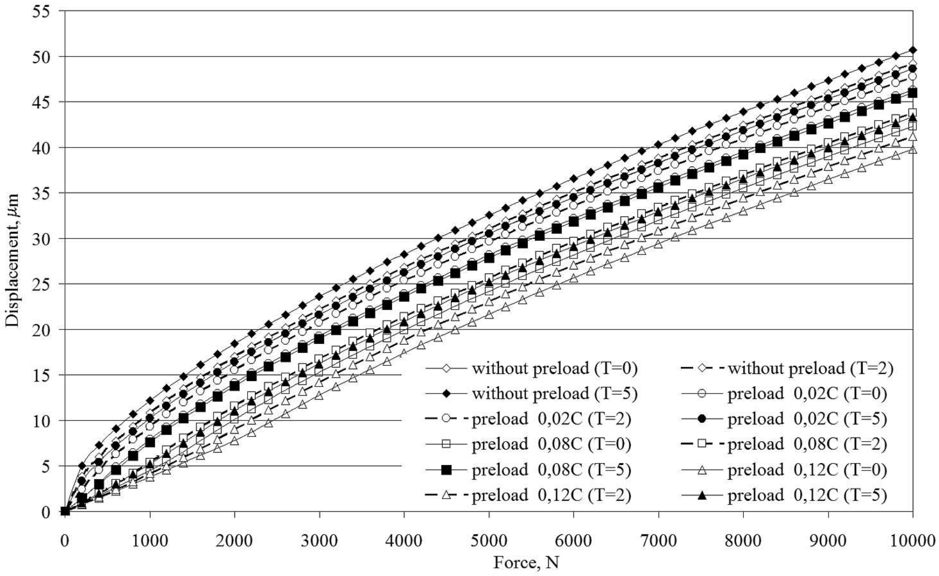

Fig. 9. Characteristics of displacements of the block-rail system, with parallelism errors, with a preload force perpendicular to the mounting surface of the runner block

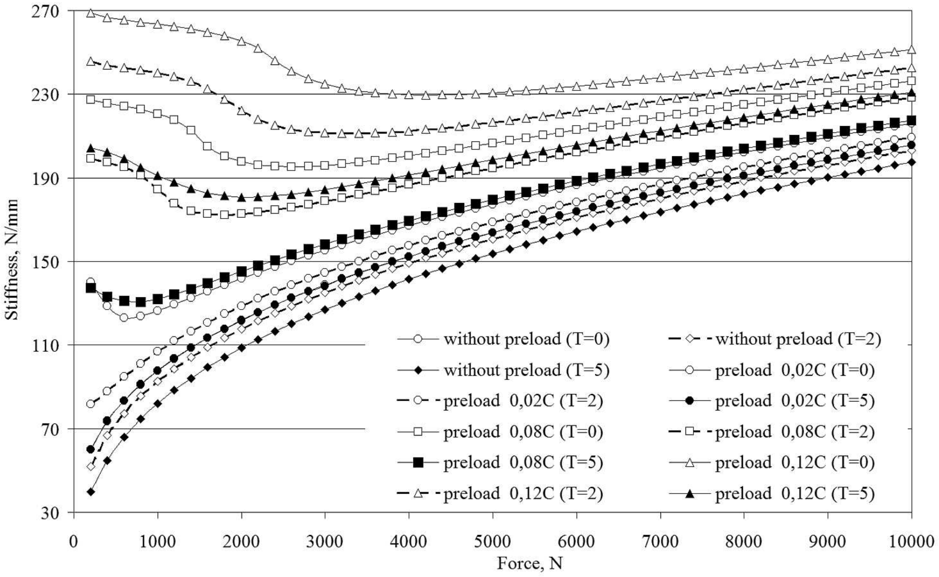

Fig. 10. Characteristics of stiffness of the block-rail system, with parallelism errors, with at preload force perpendicular to the mounting surface of the runner block

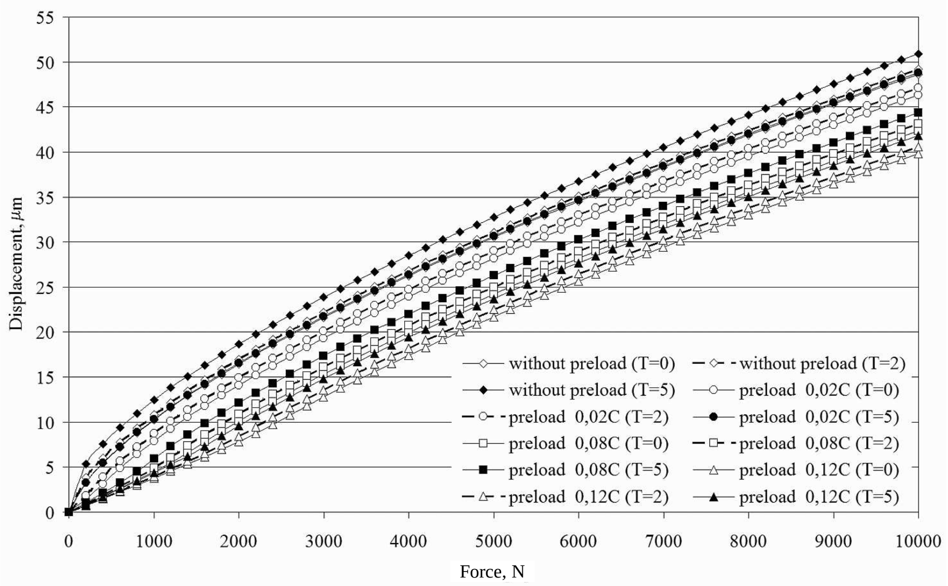

Fig. 11. Characteristics of stiffness of the block-rail system, with linearity errors, with the preload force perpendicular to the mounting surface of the runner block

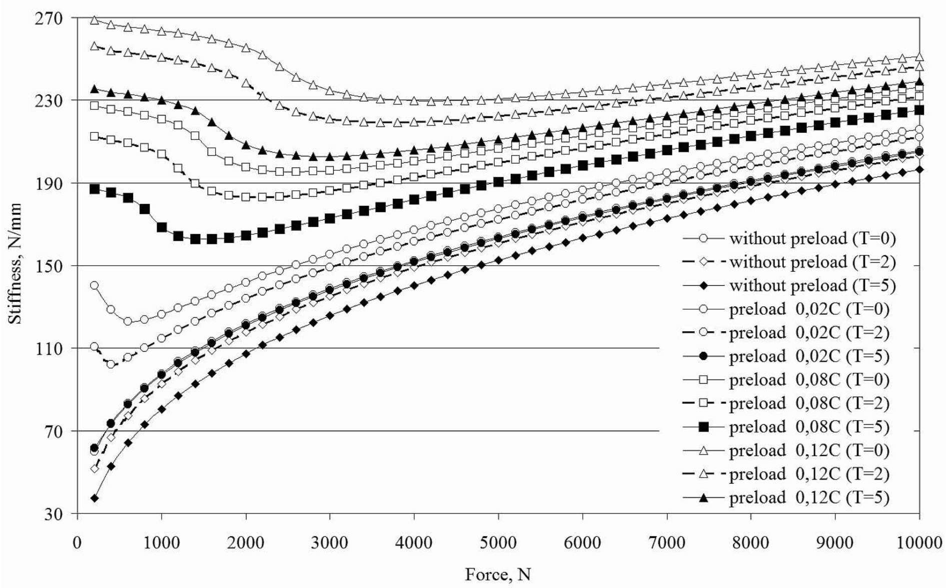

Fig. 12. Characteristics of stiffness of the block-rail system, with linearity errors, with a preload force perpendicular to the mounting surface of the runner block

6. Conclusions

The presented graphs reveal the significant effect of errors in the production of rolling elements in a guide rail systems (here referred to as ball diameter errors) in their static characteristics. This impact increases with the increase in preload and is most visible at 8 and 12% of the dynamic load capacity (Fig. 6 and 7). A comparison of the model with the greatest errors in this study ($T = 5$ μm) with a model without errors ($T = 0$ μm) shows that the stiffness of the systems in the direction of force F – in the range of its low values – is reduced even a few times.

Comparing the results of the presented analyses for various preloads (0.02, 0.08, and 0.12 C) with the data provided by the manufacturer, considerable differences can be shown in the values of the coefficients of stiffness at the same load capacity. It is particularly evident for lower loads (up to 4 000 N). This information may be important for the design of machines and technological devices requiring high stiffness.

In conclusion, the presented method of testing the impact of geometric errors on the the static characteristics of guide rail systems can be a complementary tool in the selection of guide rail systems, complementary to the procedures recommended by the manufacturers. This study shows the significant impact of geometric errors on the static characteristics of guide rail systems. Particularly noteworthy is the declining influence of these errors with an increase in preloads.

However, in many cases the application of high preloads is not recommended for operational reasons, e.g. because of an increase in positioning errors. In such cases, systems with low preloads must also ensure a high quality of mounting, since the errors are caused not only by the faulty production of elements but may also be due to inappropriate assembly.

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Received in January 2012