DESIGNATION OF A NORMAL STIFFNESS CHARACTERISTIC FOR A CONTACT JOINT BETWEEN ELEMENTS FASTENED IN A MULTI-BOLTED CONNECTION

Rafał GRZEJDA

West Pomeranian University of Technology, Szczecin, Faculty of Mechanical Engineering and Mechatronics
Department of Mechanics and Fundamentals of Machine Design
19 Piastów Ave., 70-310 Szczecin, Poland, fax: +48 91 4494564, e-mail: rafal.grzejda@zut.edu.pl

Summary

Research of a contact joint between elements fastened in a multi-bolted connection are presented. The tests were realized with use of the INSTRON 8501 Plus servohydraulic fatigue testing machine and the original instrumentation performed earlier in the Department of Mechanics and Fundamentals of Machine Design at the Technical University of Szczecin [1]. A form of the normal stiffness characteristic for the studied contact joint is proposed.

Keywords: multi-bolted connection, contact joint, stiffness characteristic

WYZNACZANIE NORMALNEJ CHARAKTERYSTYKI SZTYWNOŚCIOWEJ STYKU MIĘDZY ELEMENTAMI ŁĄCZONYMI W POŁĄCZENIU WIELOŚRUBOWYM

Streszczenie

Przedstawiono badania doświadczalne połączenia stykowego pomiędzy elementami łączonymi w połączeniu wielośrubowym. Badania zrealizowano za pomocą maszyny wytrzymałościowej INSTRON 8501 Plus oraz oryginalnego oprzyrządowania wykonanego wcześniej w Katedrze Mechaniki i Podstaw Konstrukcji Maszyn Politechniki Szczecińskiej [1]. Zaproponowano postać normalnej charakterystyki sztywnościowej dla badanego połączenia stykowego.

Słowa kluczowe: połączenie wielośrubowe, połączenie stykowe, charakterystyka sztywnościowa

1. INTRODUCTION

One of the most important steps of a machines design process is experimental verification of its models. Through it, it can be gain an information on the correctness of the design assumptions adopted in the model. This applies particularly to a systems of many bodies being in a contact, like in case of multi-bolted connections [6].

In the previous papers [8, 9] some results of modelling and calculations of an asymmetrical preloaded multi-bolted connection, subjected to an external normal load, were released. The introduced models deal with joints of a flexible flange and a rigid support (Fig. 1). Examples of such types of joints are connections of plates and covers with a crossrail or a column of a machine tool or a connection of a head with a car's engine block.

The most significant feature of the proposed method of multi-bolted connections' modelling is treating them as a system composed of three subsystems, which are: the set of bolts, the joined element and the contact layer. However, an important property of the contact layer subsystem is a possibility of inclusion of experimental mechanical contact characteristics between joined elements into the model.

To validate the introduced multi-bolted connection's model, experimental investigations on the special laboratory stand were performed [4].

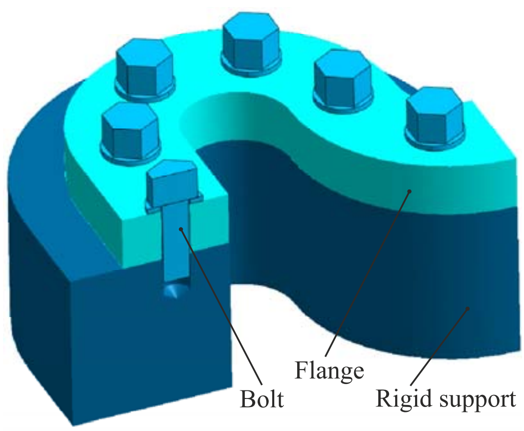

Fig. 1. Fragment of a multi-bolted connection

The scope of research was divided into two parts. In the first part the preliminary tests were carried out and in the second part the main studies were realized. The main studies were described in the paper [4]. Their aim was to measure the forces in bolts occurring in the preloaded multi-bolted connection, subjected to an external normal load. The preliminary tests consisted in determining of the normal stiffness characteristic for the contact of elements joined in the multi-bolted connection. Description of execution of these tests and their results are presented in this paper.

2. OBJECT OF RESEARCH

Research were executed using the INSTRON 8501 Plus servohydraulic fatigue testing machine. Equipment limitations imposed on the machine indisposed completion of the preliminary tests directly on the laboratory stand. Therefore, the stiffness characteristic of the contact joint between elements fastened in the multi-bolted connection were determined indirectly. For this purpose a pair of cylindrical samples representing the relevant joined elements of the main laboratory stand were used (Fig. 2).

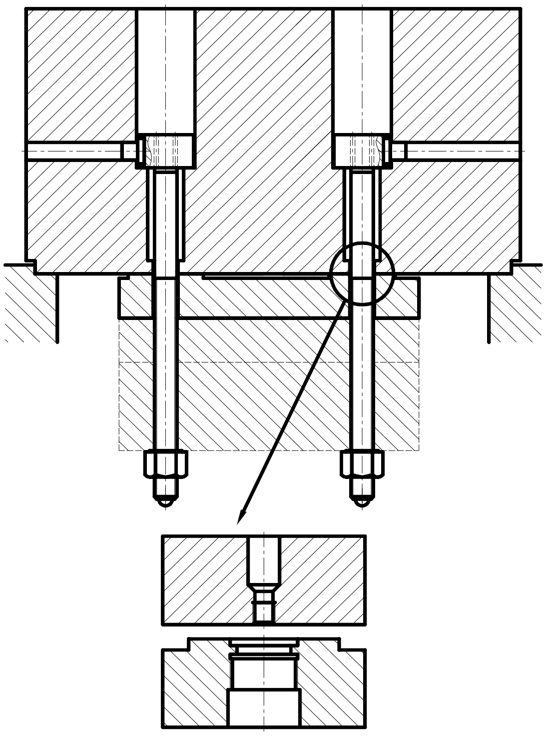

Fig. 2. Scheme of the multi-bolted connection and equivalent samples

The samples were made from steel C15 and 18G2 used as material for the construction of the flange elements – three plates with thickness h (for $h \in \{20\text{ mm}, 40\text{ mm}, 80\text{ mm}\}$ – and the rigid support. The contacting surfaces of the cylinders' bases of the samples were mechanically grinded by the method and process parameters in accordance with the method and process parameters adopted for grinding of the flange elements and the support. On the basis of measurements of the surface texture, it has been shown that the surfaces of the samples may be regarded as synonymous with the surfaces of the elements joined in the multi-bolted connection [3].

Research were realized with use of the original instrumentation performed earlier in the Department of Mechanics and Fundamentals of Machine Design at the Technical University of Szczecin [1]. A general view of the test stand and its scheme are shown in Fig. 3 and Fig. 4.

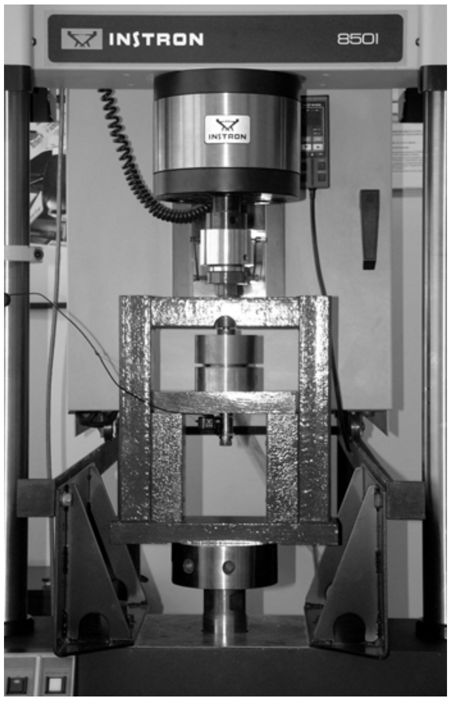

Fig. 3. View of the test stand

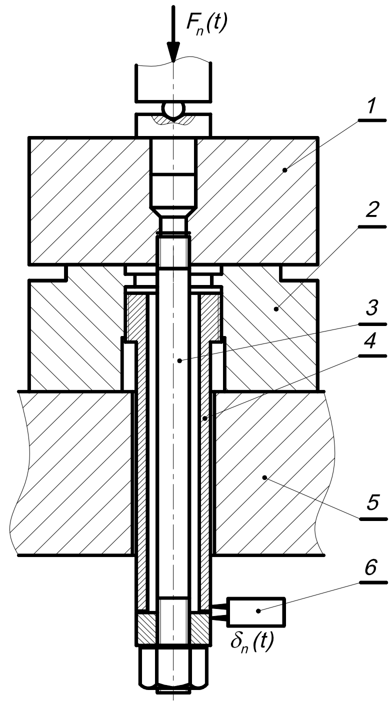

Fig. 4. Scheme of the test stand

The contact joint is created by the surfaces of the upper sample (1) and the lower sample (2). The samples are positioned on the plate (5), mounted in a rigid frame. The frame is placed between the upper head of the testing machine and its table. Surfaces of the samples are loaded by the force $F_n(t)$. Contact deformations $\delta_n(t)$ of the set of the samples are measured with the extensometer (6) as axial displacements of the pilot bar (3) screwed into the hole in the sample (1) relative to the sleeve (4) screwed into the hole in the sample (2).

Process load control and registration of results were managed by the INSTRON WAVE MAKER computer program.

3. RESULTS OF RESEARCH

The established course of the clamping force $F_n(t)$ and the course of resulting contact deformations $\delta_n(t)$ are shown in Fig. 5. For depiction of these curves, the following types of lines are adopted:

- the continuous line, which shows contact deformations $\delta_n(t)$,
- the dotted line, which shows the clamping force $F_n(t)$.

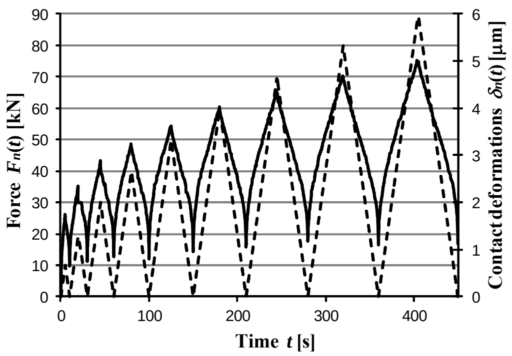

Fig. 5. Load and contact deformation characteristics as a function of time

On the grounds of so obtained data, one achieves a dependence between contact deformations $\delta_n(t)$ and contact pressure $p_n(t)$. It can be plotted in a form shown in Fig. 6.

The curves specified for subsequent cycles of loading and unloading of the contact joint are characterized by a hysteresis. Approximation of the experimental data was carried out for a range of the data corresponding to the loading cycles.

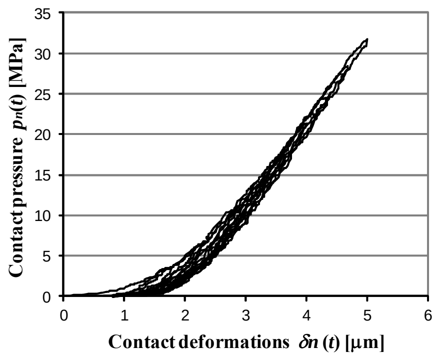

Fig. 6. Contact pressure as a function of contact deformations

Experimentally determined normal stiffness characteristics can be described as:

- a power function [5]

$$p_n = c_n \cdot \delta_n^m \quad (1)$$

- a second degree polynomial [7]

$$p_n = b_1 \cdot \delta_n + b_2 \cdot \delta_n^2 \quad (2)$$

- an n-th degree polynomial [2]

$$p_n = b_1 \cdot \delta_n + b_2 \cdot \delta_n^2 + ... + b_n \cdot \delta_n^n \quad (3)$$

where: c_n, m, b_1, b_2, b_n denote the experimental coefficients.

Equations of curves characterizing the tested joint with regard to its elastic deformation, for the last loading cycle, are set up in Table 1. The parameters of these equations were estimated by the quasi-Newton method, using the Statistica computer program. The characteristics given by the formulas (1), (2) and (3) for $n = \{3, 4, ..., 7\}$ are taken into account. In the case of polynomials, statistically insignificant terms of the equations are not included. Values of the coefficient of determination R^2 for selected equations are also presented in Table 1.

Table 1. Regression equations of the analyzed experimental data

Type of the equation		Form of the equation	R^2
Power function		$p_n = 3{,}428 \cdot \delta_n^{1{,}657}$	0,997
Polynomial function	$n = 2$	$p_n = 2{,}083 \cdot \delta_n + 1{,}64 \cdot \delta_n^2$	0,995
	$n = 3$ or 4	$p_n = -0{,}461 \cdot \delta_n + 3{,}667 \cdot \delta_n^2 - 0{,}373 \cdot \delta_n^3$	0,998
	$n = 5$	$p_n = -1{,}191 \cdot \delta_n + 5{,}196 \cdot \delta_n^2 - 1{,}452 \cdot \delta_n^3 + 0{,}312 \cdot \delta_n^4 - 0{,}032 \cdot \delta_n^5$	0,998
	$n = 6$	$p_n = 4{,}980 \cdot \delta_n^3 - 3{,}056 \cdot \delta_n^4 + 0{,}762 \cdot \delta_n^5 - 0{,}069 \cdot \delta_n^6$	0,998
	$n = 7$	$p_n = 2{,}957 \cdot \delta_n^2 - 0{,}077 \cdot \delta_n^5 + 0{,}028 \cdot \delta_n^6 - 0{,}003 \cdot \delta_n^7$	0,998

The characteristics were tested for both their simplicity and fidelity of data mapping. On the basis of investigation of obtained functions, for modelling of the contact layer between elements joined in the multi-bolted connection the power function is selected.

4. CONCLUSION

In the paper an approach to study of the contact joint between elements fastened in a multi-bolted connection is presented. Research were performed using equivalent samples representing the relevant elements of the connection. The contact surface of the samples was reduced in relation to the contact surface of the elements. Consequently, a sufficiently high level of contact pressure between joined elements was attained. It was needful to set down the normal stiffness characteristic of the tested multi-bolted connection. As the form of this characteristic, the power function is proposed. The chosen function was used for modelling and calculations of the tested multi-bolted connection. Results of this analyses were described in [3, 8, 9].

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Rafał GRZEJDA received a M.Sc. degree in 2000 at the Technical University of Szczecin and Ph.D. Eng. in 2009 at the West Pomeranian University of Technology, Szczecin (WPUT). He is currently employed at WPUT as an assistant professor (an adjunct). His main area of research is modelling of multi-bolted connections with use of the finite element method.