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Experimental verification of the properties of fibres for the mechanisms based on parallel kinematic structures

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Abstract. The paper was written in the framework of research in mechanisms of the increased mobility on the basis of parallel kinematic structures, for which a fibre control instead of rigid elements is designed. The experiment is focused on the verification of the fibre properties in simplified mechanical systems such as motion on an inclined plane, vibration of a moving weight hanging on a fibre and fibre interaction with two types of pulley. The arrangement and instrumentation of the experimental stand and of the system for the measurement of position and axial forces in a fibre are described. The results should serve for tuning the computational model, the results of which are also presented in the framework of specific experiments.

Introduction

Fibre control instead of rigid element design is proposed due to the achievement of a lower moving inertia of parallel kinematic structures. The static and dynamic behavior of the fibres has to be studied to ensure that the required characteristics of structure control mechanism would be obtained.

The aim of work presented in this paper is to show the investigation of the carbon fibre dynamic behavior on very simple kinematic arrangement which does not quite correspond to the final parallel mechanism of the manipulator under future consideration, but is suitable for tuning the computational model. Two sets of tests were performed. At the first test series, the simple fibre mass system was used consisting of free moving weight coupled with a frame by a fibre. At the second test series the fibre led over the pulley was driven with one driving mechanism to obtain the responses of the fibre mass system to several displacements forms exciting the second fibre end. A carbon fibre with a silicone coating was used for the experiments [1].

Experimental Set-up

Basic Mechanical Design. To ensure the unidirectional free motion of the mass connected to the fibre, the linear guided table (LGT) was used (mass about 3 kg), equipped with an upper plate for positioning the additional mass (Fig. 1). The side wall of this plate was provided with the linear grid of the incremental optical displacement measuring system. The optical head was positioned on the bottom stationary plate, served for clamping of the guiding bed to the basic plate or to the turning device at the same time.

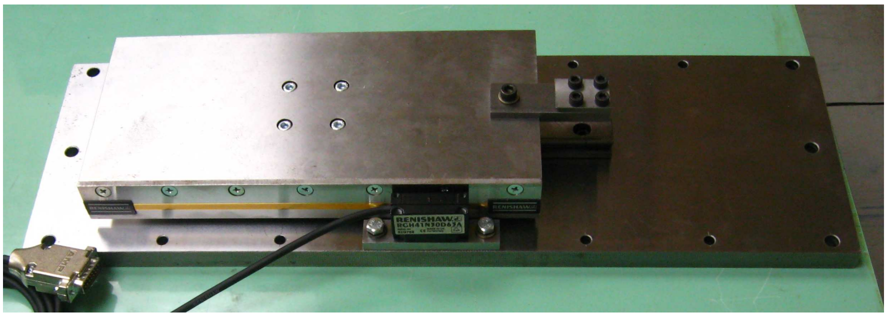

Fig. 1. Used linear guided table for the tests with optical incremental measurement system.

The length of the fibre was 1830 mm. Both ends of the fibre were stacked down between two steel plates to prevent their slipping and were bolted on the movable or stationary table through the loading cell. The loading cell consisted of the rectangular hollow profile of dimension 15×15 mm and wall thickness of 1 mm (Fig. 2). The sensitive semiconductor Kyowa strain gauges were used as measuring elements.

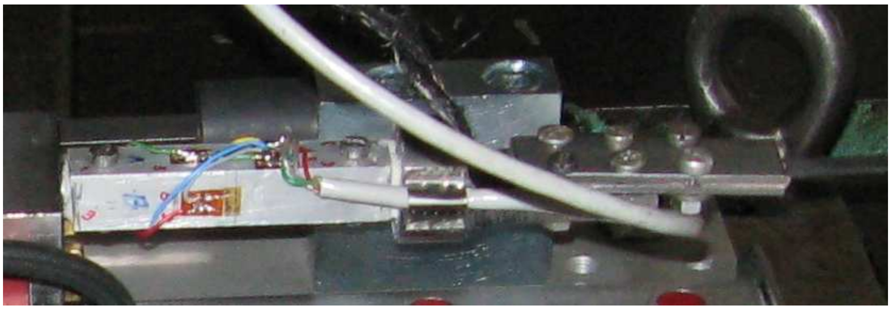

Fig. 2. A developed test loading cell and system used for fibre clamping.

Simple Fibre Mass System. The initial investigations of fibre properties eliminating the influence of the drive and the pulley were performed on weight-fibre set-up on a vertical or an inclined plane (Fig. 3).

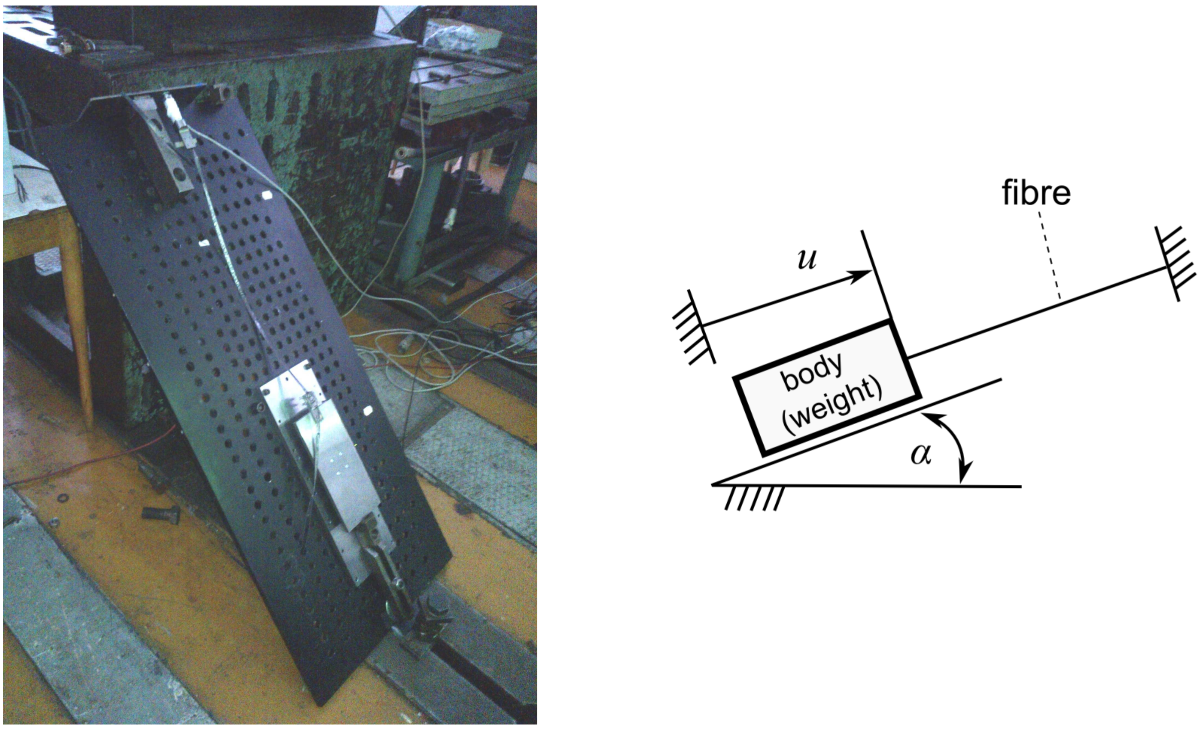

Fig. 3. Simple fibre mass system set-up.

One end of the fibre was fixed on the loading cell; the other end on the LGT (i.e. weight). All equipment was clamped on a basic plate, which enables to change the position from vertical direction up to 60 degrees from the vertical directions just forming an inclined plane.

Driven Fibre Mass System. All other investigations were made with the fibre led over one pulley (diameter of 80 mm) and driven with one linear motor (producer VÚES Brno) with the maximum displacement range of 100 mm. This linear motor was driven by means of the Emerson Unidrive SP frequency converter. The loading cell was fixed on the drive during the tests.

In the beginning the friction force tests were performed at horizontal position of both the LGT and the drive for several driven velocities and three weights of the LGT (at these tests was the investigated system without the pulley).

Fig. 4. Friction force test (drive wire displacement sensor on the right side).

Next two basic set-ups were used. The first set-up was prepared with the horizontal position of the drive and fixed rotation of the pulley bracket. The vertical position of the drive and the pulley bracket rotatable around vertical axis was used for the second set-up. The second set-up was further arranged first symmetrically with linear motor, pulley and LGT in one vertical plane and secondly asymmetrically with shifted LGT from this plane (Fig. 5).

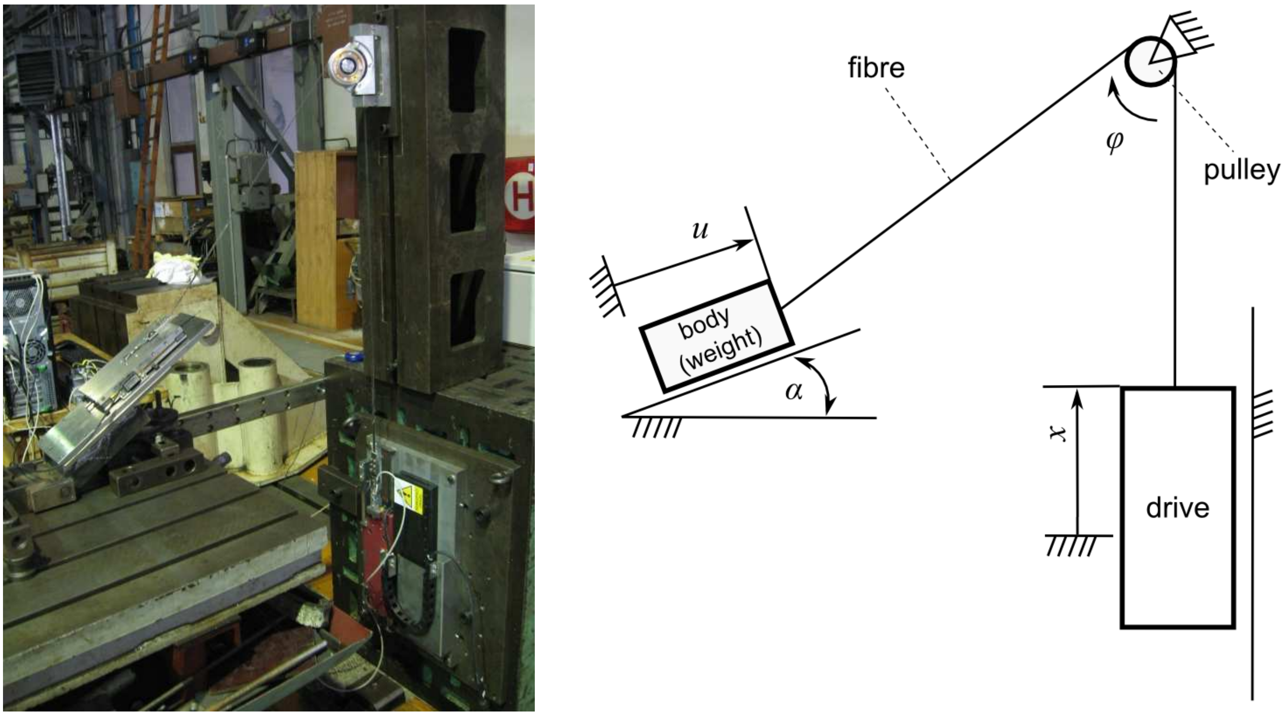

Fig. 5. Driven fibre mass system (second set-up, asymmetrical arrangement).

Control, Measurement and Data Acquisition. The actuation of the linear motor was made with the help of the Emerson Unidrive SP frequency converter using the application developed in the LabView environment. Drive exciting signals can be of a rectangular, a trapezoidal and a quasi-sinusoidal shape and there is a possibility of variation of a signal rate. The maximum velocity can be 300 $mm{\cdot}s^{-1}$. The displacement of the linear motor was measured by means of the Renishaw RLE 10 fibre optic laser interferometer using a corner reflector. The LGT displacement was measured with the RGH 41, 0.4 μm resolution Renishaw optical incremental read head. A steel scale 40 μm with self adhesive backing was used.

Data acquisition was realized using LabView at sample rate 2 kHz with the NI CompactDAQ digital input module NI9402 (both displacements) and the 9237 analog SG module (force), see Fig. 6.

Fig. 6. The NI CompactDAQ measuring device with two acquisition modules.

Performed tests and verification of computational models

Numerical Calculations. Both set-ups of test stand were tested experimentally and also investigated numerically using a non-linear multibody model created in the alaska simulation tool [2]. The fibre model was considered to be phenomenological and it was modeled by the forces which comprise e.g. influences of fibre transversal vibration, etc. The weight was considered to be a rigid body. When assuming the massless fibre model the system was considered two-dimensional, when assuming the point-mass model of the fibre the system was (partly) considered three-dimensional [3]. When looking for compliance of the results of experimental measurement with the simulation results influences, the following system parameters are considered: the fibre damping coefficient, the fibre stiffness and the friction force between the weight and the prismatic linkage. The influence of those parameters on time histories of the weight position and also on time histories of the force acting in a fibre was evaluated partly visually and partly on the basis of the value of correlation coefficient between the records of the experimental measurement and that of the simulation results. Results of simulations were compared with the results of simulations obtained when considering “starting” values of the phenomenological model. “Starting” value of the fibre stiffness was measured on a tensile testing machine. “Starting” value of the fibre damping coefficient has been derived from the value of the fibre stiffness. Fibre stiffness and fibre damping coefficient were considered to be constant (in a current phase of the fibre behavior research). Friction force course (in dependence on the weight velocity) was considered nonlinear. Information in detail about the calculation model is in [3] up to [6].

Tests with Simple Fibre Mass System. The weight (Fig. 3) was lifted using the LGT to a certain height (from 5 to 20 millimeters) and then let to fall in the vertical direction or to slide down the inclined plane. A carbon fibre (fibre length 599 millimeters; fibre mass 1.63 grams) was used at all of the tests. In the first case the weight was let to fall by free fall (vertical position), in the other cases the weight was let to slide down the inclined plane of angles 45° and 30°. Time histories of the weight (LGT) position and of the force acting in the fibre were recorded. An example of comparison of measured and calculated displacement and force during sliding down the 45°-inclined plane is presented in Fig. 7.

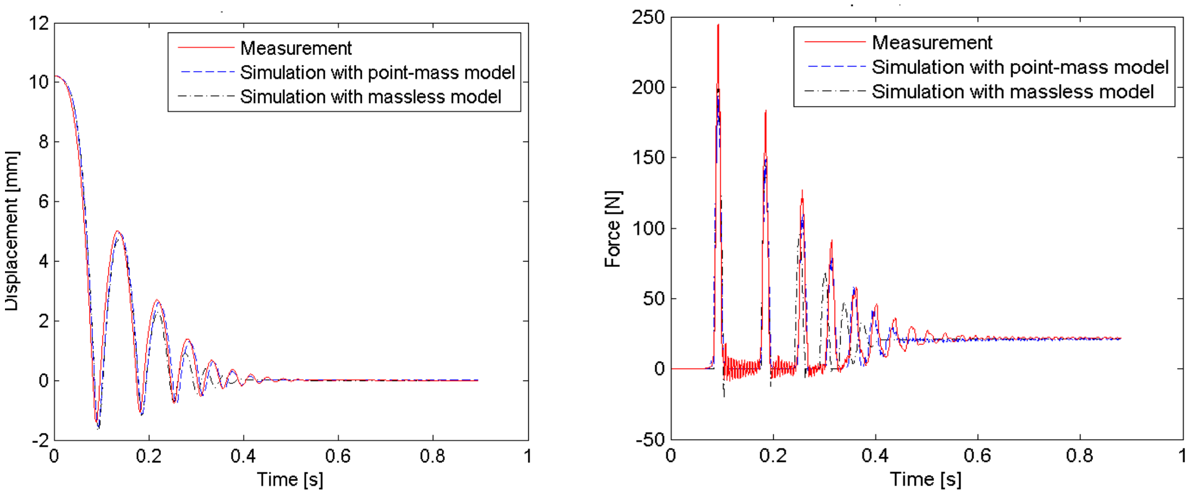

Fig. 7. Example of measured and calculated time histories of displacement and force at sliding down the inclined plane of 45°.

Tests with Driven Mass System. The fibre was excited by the set of 5 trapezoidal or sinusoidal drive displacements at various amplitudes and velocities. The presented example is valid for vertical arrangement of the linear motor, symmetrical position of LGT and the angle of inclined plane $\alpha = 30°$ and the pulley-fibre angle $\varphi = 120°$ (see Fig. 5).

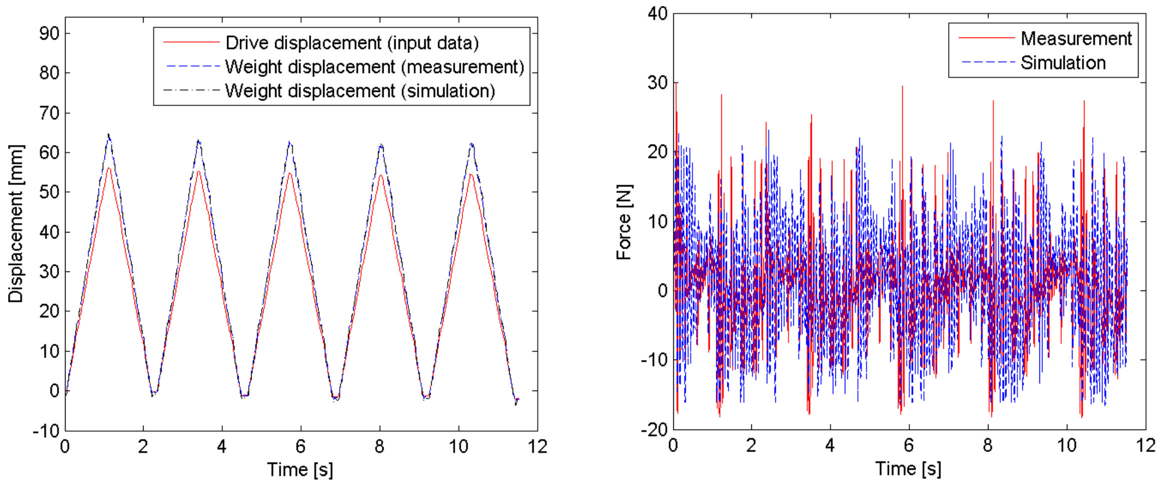

Fig. 8. Example of measured and calculated time histories of displacement and dynamic force in fibre during slow trapezoidal displacement of the fibre.

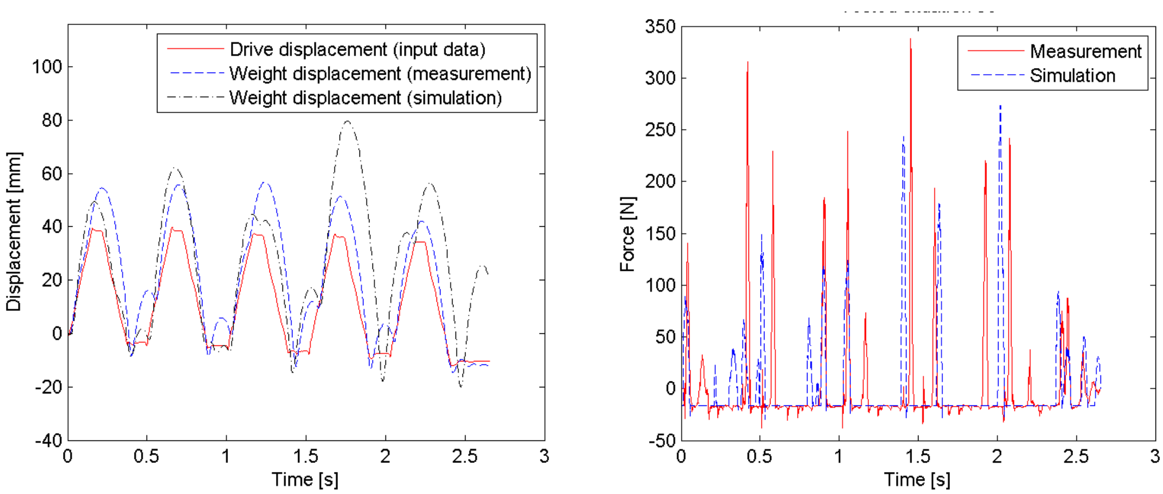

Fig. 9. Example of measured and calculated time histories of displacement and dynamic force in fibre during trapezoidal displacement of the fibre at higher velocity.

Time histories obtained during slow drive motion represents symmetrical distribution of acting forces and the fibre is not relieved during the tests; however they are not sufficient for the validation the numerical model of the fibre because the change of the input parameters does not influence the calculated time histories (Fig. 8). The velocity of the linear motor was about 90 $mm \cdot s^{-1}$ and the force 30 N. The results obtained at higher velocities are better for modeling (see Fig. 9), when the maximum velocity was 300 $mm \cdot s^{-1}$ and the maximum force approximately ten times higher than in previously mentioned test.

Nevertheless, the possibility of performing the experimental measurements with other time histories of drive motion or with different mechanical geometrical arrangement of experimental stand will be analyzed and realized in future to validate the phenomenological model of the fibre in a better way. The reason for this is that at all the simulations when changing the computational model the time histories of dynamic force acting in the fibre are different (more or less) but their character remains the same.

Summary

From the achieved results it is evident that in this stage it is difficult to create the phenomenological model of the fibre in a qualified way on the basis of so far achieved results of performed tests. The possibility of performing experimental measurements with other time histories of a drive motion or with different geometrical arrangement of experimental stand will be analysed.

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