COMPUTATIONAL MECHANICS 2022
37th conference with international participation
Srní
November 7 - 9, 2022

Device for measuring the stiffness of the tensile nylon springs

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1. Introduction

Twisted and coiled nylon fiber actuator represents a soft actuator (also called as an artificial muscle) which is suitable to realize smooth and soft motion of machines and robots. This type of actuator is fabricated by twisting nylon fibres (e.g. fishing line) into helical state and in the final, it looks like a preloaded tensile nylon spring (Fig. 1 left).

Cold nylon spring actuator is stretched due to tensile load and its shortening is realized by heating. Thus, the actuator's operation can be controlled by changing its temperature. Actuator heating is realized by hot air blowing, warm water bypass or by electric Joule heating (Fig. 1 right). The advantage of this actuator is simple and cheap production, outstanding power density and large deformation. These actuators are referred to as Twisted-Polymeric-Fibre Actuators (TPFA), while the nylon fishing line is commonly used to produce them. A more extensive overview of TPFA can be found in [2, 4, 5].

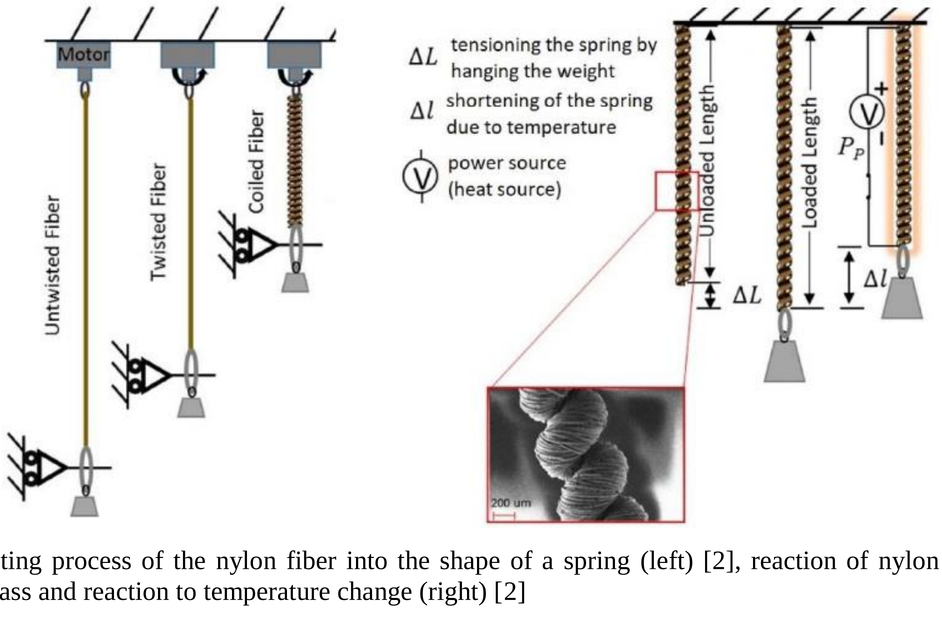

Fig. 1. Twisting process of the nylon fiber into the shape of a spring (left) [2], reaction of nylon fiber spring on adding mass and reaction to temperature change (right) [2]

To analyze the functionality of a nylon spring by the computational methods [3], it is necessary to know its mechanical and thermal properties. This paper presents a device that can be used to measure the basic mechanical property of nylon springs - tensile stiffness. Spring stiffness is measured either by a quasi-static test (stretching of the spring) or a dynamic test (mass vibration) [1]. Data acquisition system is implemented using the Arduino platform.

2. Measuring device

From a technical point of view, the device consists of a supporting structure, two strain gauge load cells, a linear actuator with a built-in potentiometric position sensor, control electronics and a touch screen (Fig. 2). [1]

Linear actuator is used for continuous stretching of the spring and is powered through a driver for DC motor. Load cells measure the tensile force in the spring. Voltage signal from the load cells is converted into digital form using 16-bit sigma-delta analog-to-digital converter (ADC). Arduino Mega controller is used as the control unit for the entire device, which also serves as a data acquisition system. Control of the measurement system is solved using a touch screen, on which the measured graphic curves for individual measurements are also drawn.

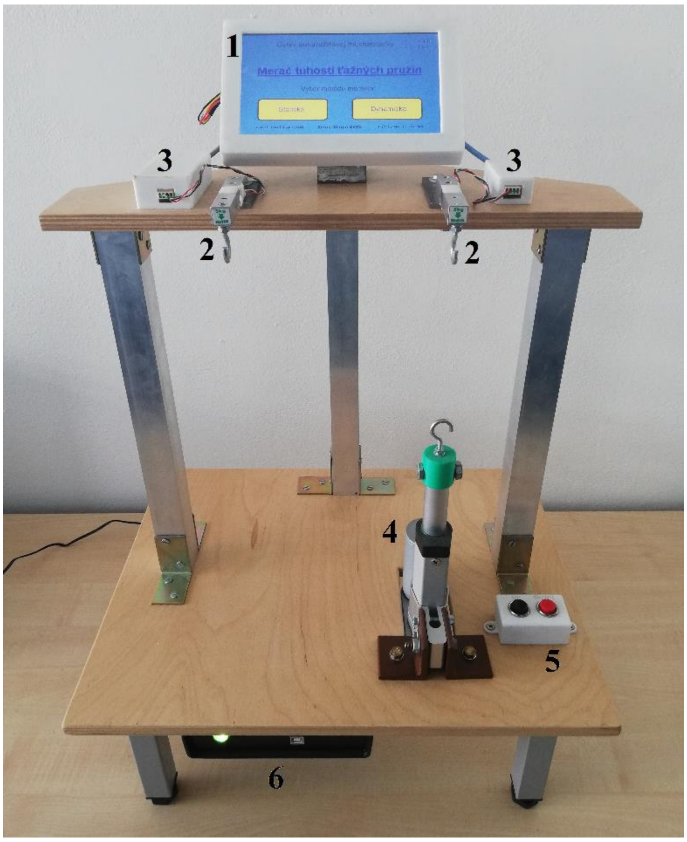

Fig. 2. Measuring device [1]: 1 – touchscreen, 2 – loadcells, 3 – ADC, 4 – linear actuator, 5 – manual control, 6 – electronics and data acquisition system

The basis of the electrical wiring of the device is the so-called shield, i.e. the expansion board with the connection pins located on the underside of the board (Fig. 3 left). These pins connect the shield directly to the Arduino Mega microcontroller board. On the shield’s top side, there are connectors for other individual electronic parts and modules of the measuring and control system (Fig. 4). The shield also contains a couple of ceramic filter capacitors, a reset button, a couple of indicator diodes with their resistors, and a screw connector for 5 V power supply from DC-DC converter (Fig. 3 right).

A special voltage transducer was designed and used to measure the force in the dynamic test (Fig. 3 right). This transducer converts low voltage output (0 to 4.6 mV) from load cell linearly to usable range (0 to 5 V) for applied ADC (module ADS1115). This output voltage is proportional to the exerted force on load cell from 0 to 50 N. Both the shield and the voltage transducer were designed in KiCAD software.

For quasi-static measurement method, the load cell in combination with module HX711 is used because it is more precise (24-bit). However, data processing by the HX711 module is slower than that of the ADS1115 module and is therefore not suitable for dynamic measurements.

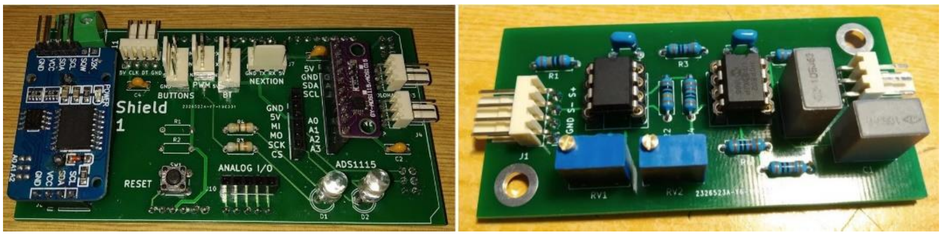

Fig. 3 Expansion board – shield (left), voltage transducer (right) [1]

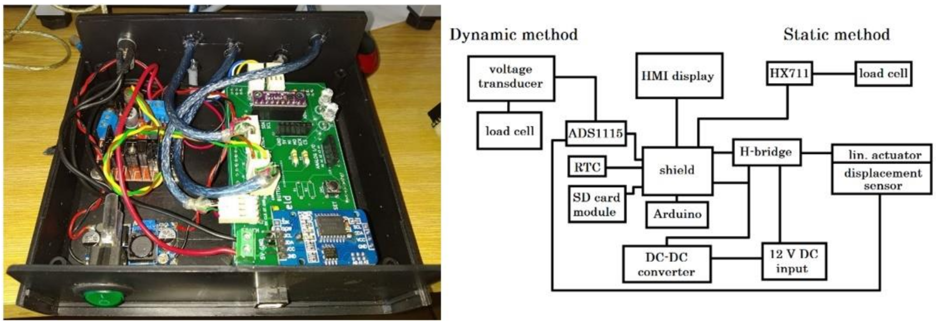

Fig. 4. Measuring and control system: actual wiring (left) and block diagram (right) [1]

3. Spring stiffness measurement procedure

Spring stiffness can be measured using two methods. The first method represents quasi-static stretching of the spring, when the tensile force and spring extension are measured. Spring stiffness in linear area of deformations is then calculated as the ratio of tensile force and spring extension by linear regression using least squares method (Fig. 5). Tensile force is measured by a load cell mounted on the upper fixed console of the device, and the spring extension is measured by a potentiometric position sensor located in the body of the linear actuator that stretches the spring.

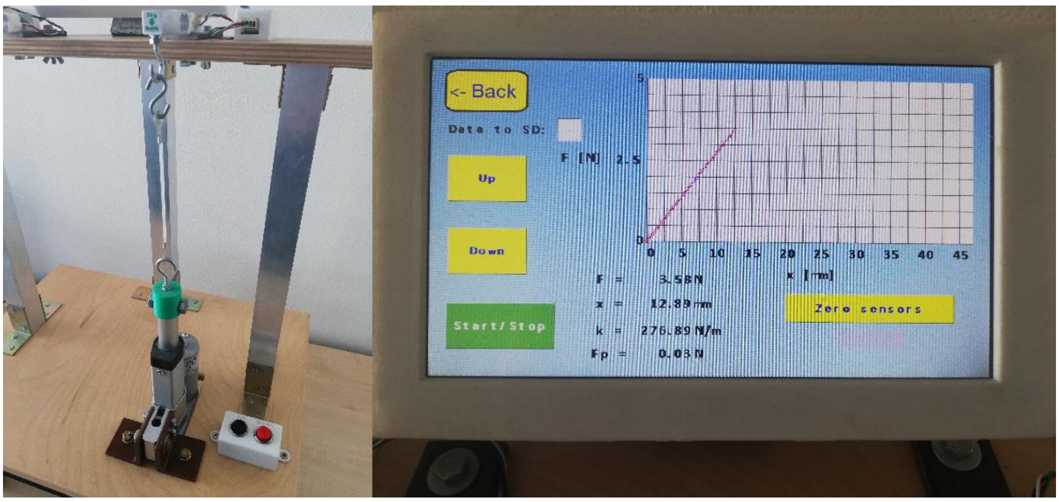

Fig. 5. Quasi-static measurement of the spring stiffness

The second method is a dynamic test, when a mass is hung on a spring attached to a load cell and allowed to oscillate (Fig. 6), it represents free vibration of 1-DOF mechanical oscillator. Before the start of the test, the load cell measures the weight of the suspended mass on the spring. Then the spring is manually stretched and released, creating a free vibration of the system. Load cell measures the time course of the force in the spring and natural frequency of the system is calculated using FFT (Fast Fourier Transform). Spring stiffness is then calculated from the known mass weight and system's natural frequency.

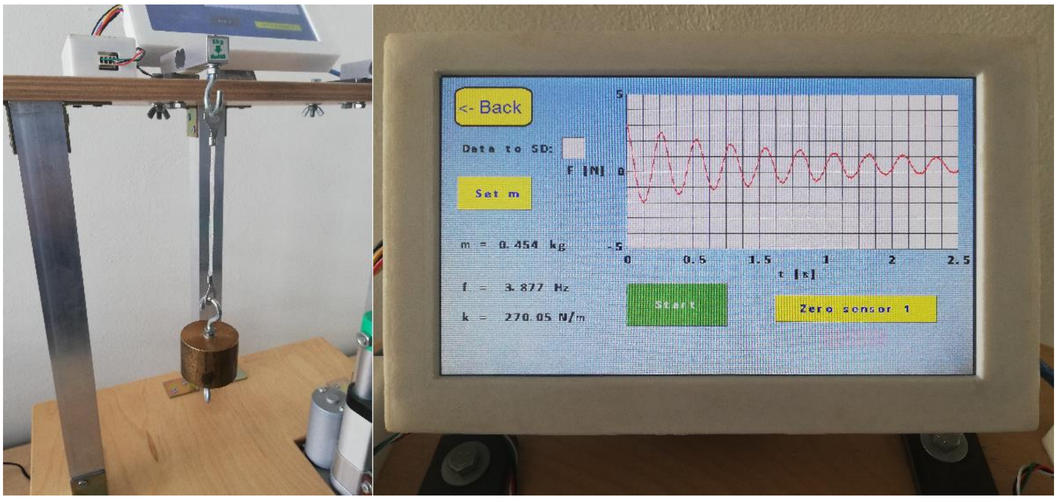

Fig. 6. Dynamic measurement of the spring stiffness

4. Conclusions

Due to the relatively large material damping of the nylon springs, the stiffnesses measured by both methods are slightly different. Better agreement is obtained when the steel springs are measured because their material damping is minimal.

The measuring device has the following advantages: it is powered only by 12 V DC power supply, the device is light and easily portable, touch screen control that also displays the measurement results, the possibility of transferring measured data to a PC using SD card, and it is suitable in education process in the mechanics.

Acknowledgements

This work was supported by the Slovak Research and Development Agency under the contract No. APVV-19-0406, by Grant Agency VEGA, grant No. 1/0416/21 and by Grant Agency KEGA, grant No. 011STU-4/2020.

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