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Analysis and Study of Vibrations of a Clamping Device Used for Winding Carbon Fibers into the Core of a Frame

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Abstract: Lightweight composite frames can be significant structural components in some transportations, flights and military applications. Nowadays composite frames can be used, for its specific properties, in many fields of industry. The main problem is how to use automatic applications for winding filaments of the carbon fibres on a closed spatial shaped core of product frames, that has been still doing by the hand manufacturing. For automatic production could be used unique prototype of robotic technology, which allows winding of the carbon fibres on closed shape into the core of a frame. The biggest problem of the clamping device, used for the closed frames, are their vibrations and resonance caused due to the rotary motions. The vibrations and resonance negatively affect the process of carbon fibres winding. This article describes experimental and numerical analysis, carried out in laboratory of applied mechanics, focused on to the influence of vibrations of the clamping device on the final quality of winding structures.

Keywords: Measurement; Numerical Modeling; Vibration; Winding; Carbon Composite; Deformation.

1 Introduction

The main parameter of the newly developed designs solution of machines parts aimed primarily to the weight reduction and also an increase proportion of energy-efficient recycled and recyclable materials while is need to maintain them the same or even better properties. This process is a system solution which can satisfy the required functional and mechanical properties. Lots of research aimed to develop new technologies to using advanced materials [1–3], leading to design lightweight composite machine parts like are in our case the closed frames. Generally are the frames and framed structures widely used in all technical fields. Their typical using is for example into beam parts, truss structures, stabilizers, braces, scaffolding elements, supports, railings, roof structures and supporting or non-supporting parts of some equipments and machines. It has been developed prototype of technology for winding the carbon fibers filaments to the core of opened or closed frames based on using the robots. The problem occurring during this kind of automatic winding of the carbon fibers are big vibrations of the clamping device. This clamping device is consisted of 3 cantilever arms, which are pneumatically controlled for reliable holding the core of the frames. Cantilever arms are vibrating because of non-smooth kinematic motion of some robot parts. The arises vibrations causes uneven laying of the carbon fibers onto the frame core. This article describes experimental analysis based on a study of vibrations of the clamping device used for holding the frame during winding by the carbon fibers and also considering to an optimization of the resulting surface quality.

2 Description of Solution

2.1 Problems of Clamping Device

For production of closed frame constructions is used according to [1] a winding technology. The sense of this technology lies in the wrap around of a non-bearing core with the geometrically defined shape of the resultant frame. The wrapping around was performed by carbon fibers and subsequently flooded into a matrix in an injection mold. The wrapping system consists of a winding structure - ”head” (Fig. 1), which fulfills the function of a regular laying of the fibers onto the core, that passes through the midpoint of the head as is mentioned [2]. The axis of rotation of the head is always coincides with the axis of the current cross-section of the frame core. For holding of the frame has been used a clamping device made from a beam structure. A task of this device is not only to hold the core, but also to move with the core through the winding head with a defined speed. Based on the ratio of the rotational speed of the head and a feed speed of the core are the fibers wound at the desired angle. The composite structures should in order to ensure an optimal mechanical properties lay in the 6 layers at an angle of +55 °, -20 °, -40 °, 60 °, -15 °, 40 ° (Fig. 1 top-right), that is suitable for such kind of construction due to the cross-cutting properties. Generally for a shear, bending and tensile stress is appropriate to lay the fibers in at least three layers at 45 °, -45 ° and 0 °, as is mentioned e.g. [2,4,5]. The number of layers is determined by the maximum thickness of the wrapped frame. It may not exceed the size limit in order to allow to insert the wrapped core into the mold. The core should be clamped in a space such way that allows a firmly locked bond and the core was firmly fixed in the desired position. As a suitable variant of a clamping the part has been the constructed three-arms clamp holder (Fig. 1a). The main advantage is the possibility to use only one robot with 6 degrees of freedom for attachment the frame. The principle consists in the using of the pneumatically controlled telescopic jaws, that are able to release the frame during a movement of the head, and that is why there are no collisions. The clamping device used for an attachment of the core is shown in Fig. 1 (bottom-left).

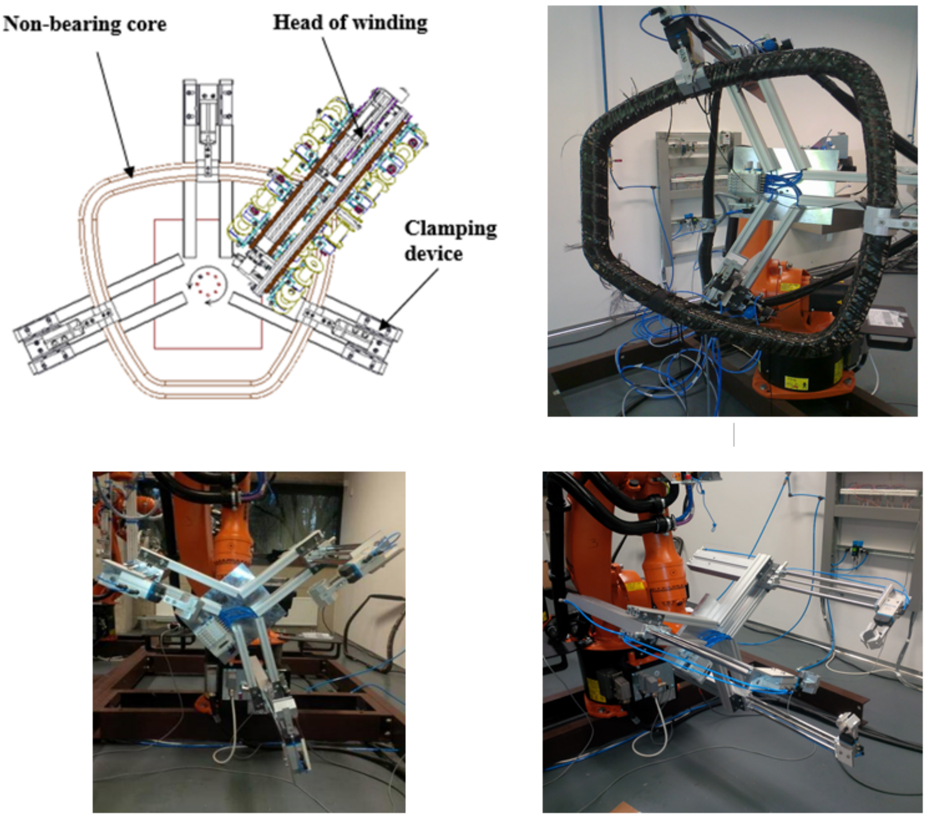


Fig. 1: Clamping Device used for Winding Carbon Fibers into the Core of a Frame.

The entire wrapping process involves a placement of the mounting jaws on the robot, which make with them a clockwise rotary motion. Parallel to this, is on a second robot attached the winding head that adapts its angle to the motion and shape of the frame. The frame is held by three clampers, which are fastened to pneumatic telescopic cylinders. At the beginning of the winding process is the frame held at three points. After moving the head to the frame and connecting of all carbon fibers onto the core begins the winding process. During the movement of the head on a trajectory of the frame release always one of the jaws the clamps and retreats out of the way of the head. The frame is thus always held with at least 2 clamps and if fact the support provides also the winding head itself due to a preloading in the fibers.

The main problem lies in a fact that during the winding process the gripping device considerably vibrates and resonates, which causes, inter alia, an oscillation of the core of the frame. This fact subsequently causes a failure to comply placing the fiber layers in the desired angular direction, which could lead to a decrease the mechanical properties of the resulting composite frame. Therefore it is necessary to identify and consequently minimized these vibrations.

2.2 Basic Theory

The gripping device is constructed of three rectangular beams which create the retaining arms as can be quite a well seen in Fig. 1d. Therefore we can consider the rectangular beam, for which is valid a general power and torque formula given by Eq. (1) and Eq. (2).

$$\rho S\left(\frac{\partial^2 z}{\partial t^2}\right)=\frac{\partial T}{\partial x}, \tag{1}$$

$$T=\frac{\partial M}{\partial x}, \tag{2}$$

where M is the torque, T the shifting force, ρ is a density and $S = hb$ is the sectional area.

If we consider that the middle neutral fiber is not extended during the bending, then applies for its length $ds = Rd\alpha$, where R is the radius and α is the angle. For the fiber at a defined distance ξ from the neutral medium fiber, is $ds^{/} = (R + \xi)\, d\alpha = (R + \xi)\, /Rds$, which implies an extension $\varepsilon = \left(ds^{/} - ds\right)/Rds = \xi/R$. Because the torque can be expressed as $M = \int \xi\varepsilon E dS = E/R \int \xi^2 dS$, where the last integral characterizes a quadratic moment of the given cross section I, E is modulus of elasticity, and it is how we can get subsequently after expression of the radius of curvature and subsequent linearization the fundamental relation according to Eq. (3):

$$M=-EI\left(\frac{\partial^2 z}{\partial x^2}\left(\left[1+\left(\frac{\partial z}{\partial x}\right)\right]^{3/2}\right)^{-1}\right). \tag{3}$$

Because it may be assumed a constant I then can be the equation of motion expressed as an oscillating beam according to Eq. (4):

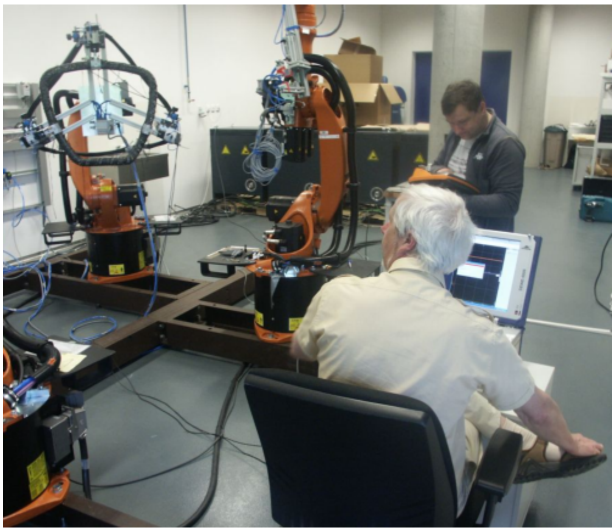
$$\rho S\left(\frac{\partial^2 z}{\partial t^2}\right)+EI\left(\frac{\partial^4 z}{\partial x^4}\right)=0. \tag{4}$$

Equation (4) can be solved in general for a harmonic motion$z(t, x) = z_0(x)e^{i\Omega t}$ with the boundary condition $z_0(0) = 0$, where we obtain frequency condition $\cos\beta l \cosh\beta l = -1$ and $\beta^4 = \left(\Omega^2\rho S/EI\right)$, where: l is the length of the beam (of an one arm of the gripping device). For the rigidity k affecting the resulting oscillation, that can be for a rectangular shape based on the Eq. (5):

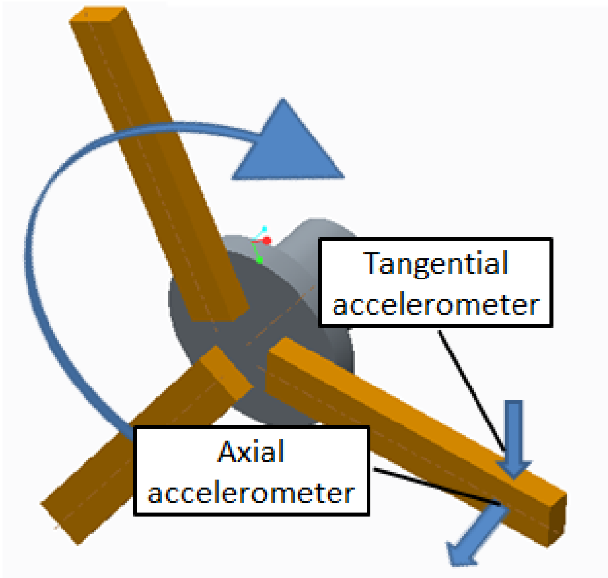
$$k=E\left(\frac{h^3 b}{\partial 4 l^3}\right)=0. \tag{5}$$

2.3 Experimental Analysis

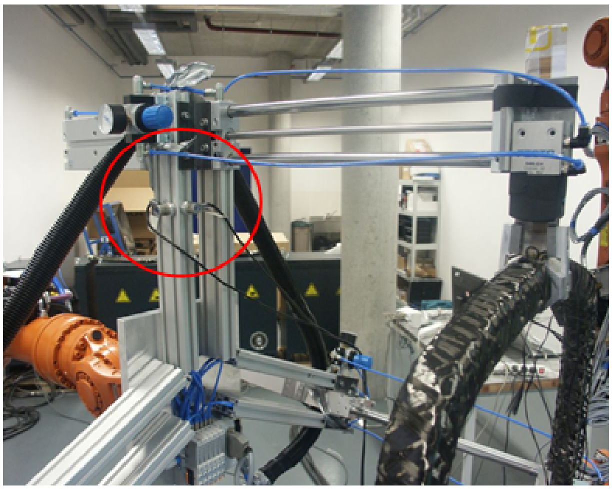
On the arm of the clamping device were mounted two identical accelerometers TLA 05, one in the axial direction and second in a tangential direction as is shown in Fig. 2. During the rotation were together measured the oscillations of the arm in an axis direction and in a circumferential direction. The oscillations were measured for the both directions of rotation.The signals from the accelerometers were displayed and recorded by measuring device DEWE5000 with sampling frequency 500 Hz. Because that the sensors measure an absolute value of acceleration, the measured signal is composed of two parts (Fig. 2c). The first of them is the harmonic course, caused by changing position of the sensor against the gravitational field due to rotation of the device. At this signal is then modulated some higher frequencies components, which describe the vibrations of the arm of the device. This fact is need to consider during evaluating the result data. The measurements determined the course of oscillation of the individual arms of the device (dependency acceleration on time). To reduce of the vibrations was necessary to re-tune the frequency of the system, which is possible in according to Eq. (4) by change of a weight or the sectional characteristic or elastic properties. In this study has been tested the using of hyperelastic element (spring) for reduction of vibration as is shown in (Fig. 2d). Hyperelastic element was mounted between the arms of clamping device, which led to reduction of the vibrations. In these experimental study was used only the passive hyperelastic element (without pneumatic control). But for a further optimization, it is assumed that the final re-tuning of the system for minimizing the vibrations will be made with an actively controlled element.



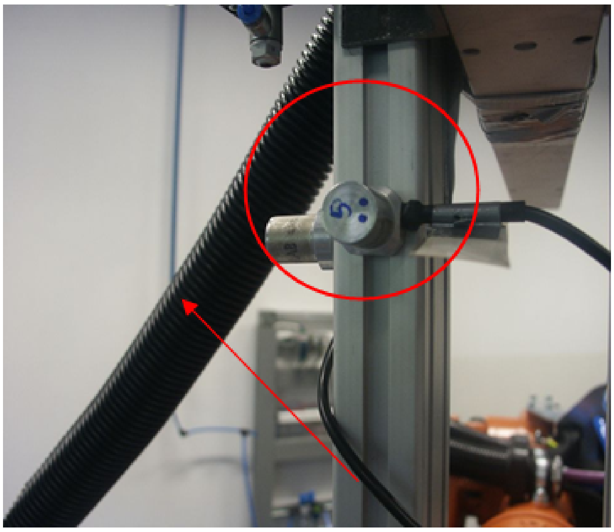
(a) preparing the measurement



(b) schematic mounting of the accelerometers



(c) placement of sensors on the clamping device

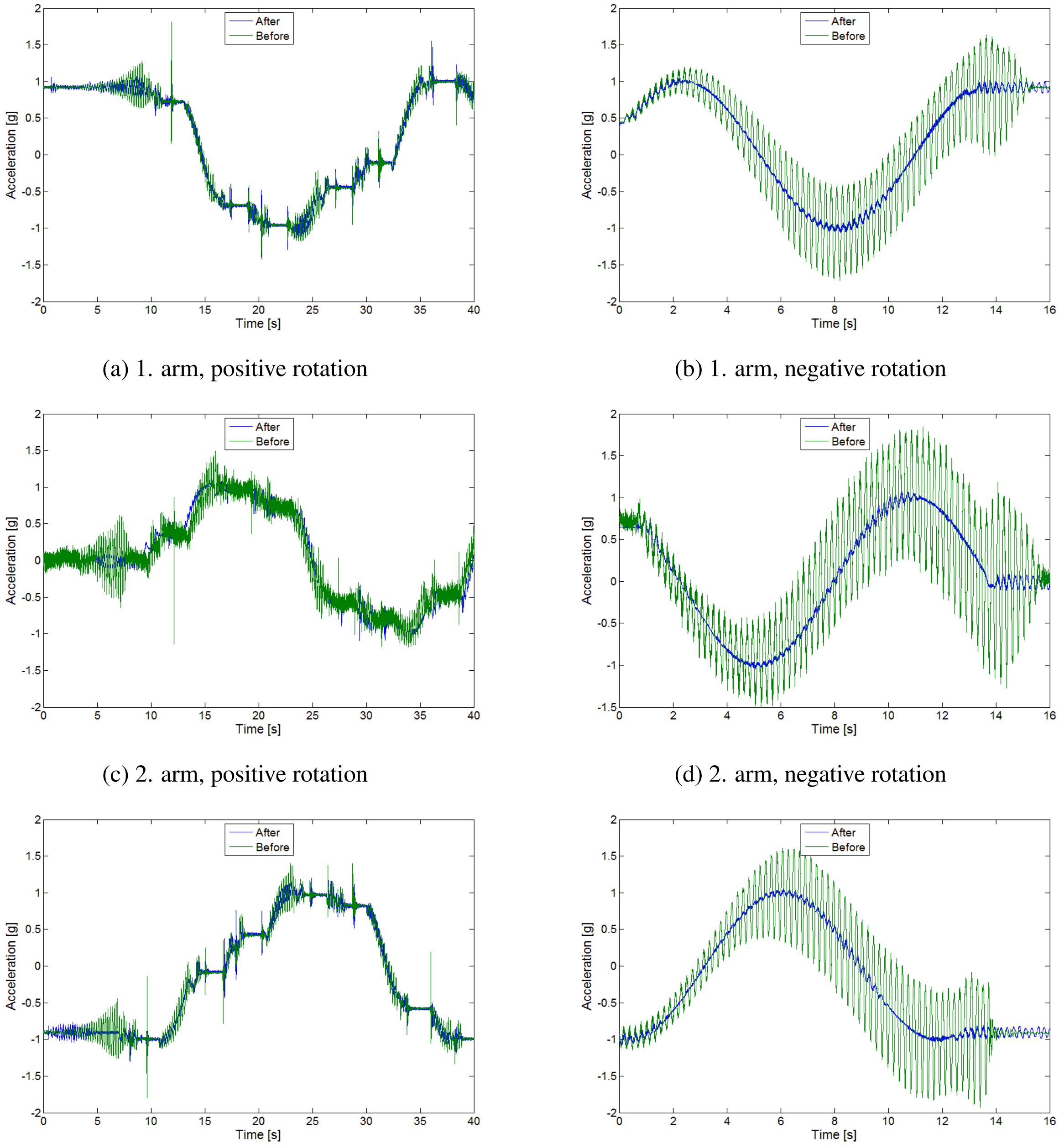


(d) detail of placement of accelerometers (red circle), the hyper-elastic element (red arrow)

Fig. 2: Experimental analysis of vibrations of a clamping device used for winding carbon fibers onto the core of a frame.

3 Results

The results of measurement for each arm was evaluated by the accelerometer located in the tangential direction (axial acceleration was minimal, respectively it was almost zero). The measurement results on the clamping device without hyperelastic element (Before) shown the uneven vibration on each arm, which caused an imbalance of the clamping device and also resonance, as is shown in Fig. 3. This uneven vibration was occurred especially in the tangential direction and the most in positive direction of rotation (rotation in a clockwise direction), when was generated significant oscillations during movement. Maximum average acceleration reached values of 2.5±0.6 g. Measurement with additional hyperelastic element (After) shown significantly reduced vibration in whole system in both of direction of rotation. Maximum average acceleration reached values of 0.4±0.15 g.



(a) 1. arm, positive rotation

(b) 1. arm, negative rotation

(c) 2. arm, positive rotation

(d) 2. arm, negative rotation

(e) 3. arm, positive rotation

(f) 3. arm, negative rotation

Fig. 3: The results of acceleration measurement.

4 Conclusion

In this publication has been carried ou the vibration analysis of the clamping device that is used for holding of the cores of composite frame structures. Used clamping device was holding the core of the frame during winding of the carbon fibers by a prototyped robotized technology. The main problem, were the vibrations of the clamping device, which were substantially oscillating due to the design of the used cantilevers. The carried measurement of the vibration with accelerometers showed a high overload 2.5±0.6 g in the tangential direction. Because of the arises vibration was the clamping device optimized by a passive hyperelastic element, which has been mounted on the device. This optimization reduced the vibrations to 0.4±0.15 g and minimized the resonations. For future is considering an using of active controlling of the used hyperelastic element.

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