Form-Finding Experiments with Resilient Cyclic Knots

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Abstract

The paper describes two recent experimental workshops lead by the author. The aim of the work was to design and build large-scale models of cyclic periodic knots made of resilient filaments. The complicated knots of this type behave as kinetic structures and form tense dome-like forms.

Last summer I organized a workshop in the VKHUTEMAS gallery for the students of Moscow Architectural Institute. The aim of the workshop was to introduce to the students some of the new ideas and principles of physical form-finding based upon the properties of resilient cyclic knots. Today, when digital form-generation methods have become predominant in architectural and design education, the experimental exploring of alternative approaches to modeling and form-finding is especially important for students. The combination of physical and digital form-finding experiments helps them to understand the mathematical background common to both of these methods.

My form-finding method derives from the fact that cyclic periodic knots made of resilient filaments behave as kinetic form-finding structures [1]. Knots of this type must have a large number of physically contacting crossings functioning as the vertices of surfaces. The crossings slide along the resilient filaments and the filaments at the same time twist around their central axis. The waves on the filaments move and change their lengths to adapt to the current disposition of the contact crossings. Thanks to these properties the knots change their geometry as a whole and create vertex or point surfaces with an arbitrary Gaussian curvature. The complicated knots of this type I designated as NODUS-structures [2].

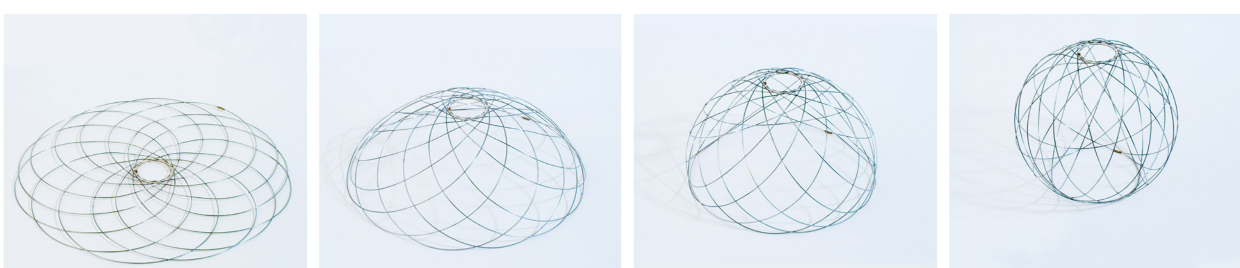

Figure 1: *Stages of transformation of resilient cyclic knot of steel wire.*

I took as a prototype one of my steel wire NODUS-structures that is a Turk's-Head-like non-alternating knot with 13 loops or bights and 12 leads (Figure 1). Though this knot was made of a single piece of wire I proposed to the students to build the scale model of a large transformable dome of 15 or 20 meters in diameter. It would be difficult and inappropriate to weave such a big structure with the single continual piece of filament material. Because we intended our model to copy not only the final shape of the dome but also the process of its assembly and erection, we decided to divide it into 13 modules of equal length corresponding to 13 loops of the knot.

The material we used for the model was fiberglass wire around 4 mm in diameter coated in orange plastic. This lightweight and non-conductive material is very suitable for the modeling of resilient cyclic knots and links though its bending abilities are limited to some minimal radius. Values of radii less than this minimum may result in breakage.

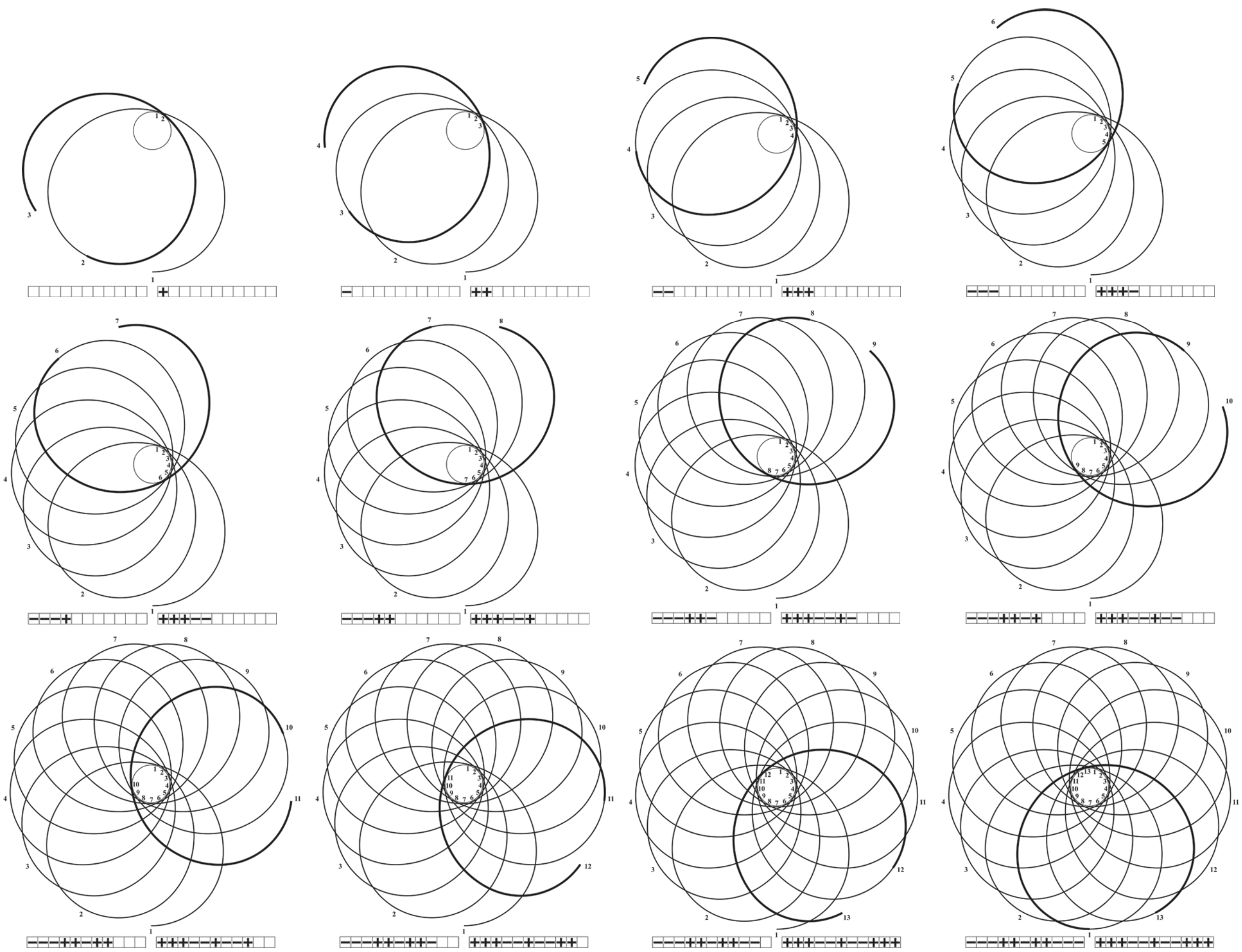

Figure 2: *Algorithm of assembling and weaving of the cyclic knot with 13 bights and 12 leads*.

We started our work by devising a detailed algorithm of the assembly process and depicting it as a series of pictures drawn on a computer (Figure 2). Each stage of the algorithm consisted of the order of connection of the corresponding module with the previous one and the order of its weaving through all of previous modules. The passing of the module in a crossing point over and under another module was marked as plus (+) and minus (−) signs correspondingly. This sequence of over- and undercrossings was necessary as a reference guide to make the structure of the chosen non-alternating knot correctly.

As a preliminary step we placed a ring in the center of the future structure and attached it to the floor. The ring was needed to fix the central opening of the structure and tense it. Then we began the assembly of the structure, adding the modular elements of the knot, forming its loops and interweaving the modules according to the algorithm (Figure 3). After we had finished all of the algorithm stages our structure was ready. We detached the central ring and tested the transformation of the structure. It worked similar to the small wire model though it was not so stiff. Then we transformed our structure into the form of a truncated sphere and added another fixing ring on the peripheral opening (Figure 4). As a result the whole structure became stretched inside the waves of the fiberglass wire and compressed at the contact crossings.

Figure 3: *Process of algorithmically assembling of fiberglass wire modules into knotted structure.*

Figure 4: *Fixing central and peripheral openings of the structure with rings and the final shape of model.*

The success of this experiment gave me the confidence to repeat it with a larger structure. This time I took fiberglass wire of 8 mm and designed a spherical NODUS-structure of 3 meters in diameter. The topology of knot was the same as in the previous experiment (13 bights and 12 leads) so I could use the same algorithm as well. Though the assembling process demanded more time and more sophisticated adjusting elements to connect the modules, the resulting dome structure was tensile and self-supporting as a large spring (Figure 5).

Figure 5: *Process of assembling of larger version of the same cyclic knot with 13 bights and 12 leads*.

The two recent experiments described in this paper deal with the simplest NODUS-structures that form parts of spherical surfaces. Because the given method of form finding may be extended to practically unlimited variety of surfaces [1] it would be interesting to continue this work and try to design and build large scale structures of such forms as hyperboloids, tori, pretzels, self crossing, one-side and knotted surfaces. This experiments may serve as good practice of physical modeling and form-finding for students as well as production of new pieces of kinetic art.

References

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[2] D. Kozlov, *Polymorphous resilient flexible shaping structures "NODUS" for space and other extreme environments*, Final Conference Proceedings Report of The First International Design for Extreme Environments Assembly, pp. 259 – 260, Houston, 1991.