DESIGN OF A PROGRAM FOR CALCULATION OF FORCING SPRING STIFFNESS

SLAVKO PAVLENKO

Technical Universtity of Kosice

Faculty of Manufacturing Technologies with a seat in Presov

Department of Technical Systems Design

Presov, Slovak Republic

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e-mail: slavko.pavlenko@tuke.sk

The presented paper deals with a design and generation of a program for calculation of stiffness and shear stress of forcing springs. The given calculation program was generated in the program of Microsoft Office through the Excel application by means of defined sequences of the individual orders. The calculation program serves for calculation of stiffness of cylindrical and conic helical forcing springs with circular and rectangular section of wire. The designed program calculates shear stress and stiffness of the spring after entering parameter values inevitable for calculation. The program contains also a database of the standardized springs which after selection of the standardized spring assures inserting of corresponding values by means of which the program prevents a user from incorrect defining of the standardized data.

KEYWORDS

application, stress, generation, torsion, parameters

1 INTRODUCTION

The presented paper deals with the design and generation of the program for calculation of stiffness and shear stress of forcing springs. In designing and generating of the aforementioned computing program the Excel program was employed which is included in the Microsoft Office pack and therefore represents the least complicated and the cheapest option for the design and generation of the aforementioned computing program. Macro represents and action or a set of actions that can be employed in automation of the tasks. Macros are recorded in the programming language of Visual Basic for Applications (programs for software generation). Higher programming languages allow programming of application software [Bicejova 2016a]. The pack includes debuggers and a simulator.

The introductory part of the paper analyses theoretical aspects of forcing springs such as classification of springs, characteristics of springs, material and structure of springs. Further on, the manual calculations are given which consequently were employed in generation of the computing program [Mascenik 2011 and 2014].

The core of the paper describes generation of the respective computing program by Microsoft Office in the Excel application by means of macros.

The conclusion contains evaluation of the use of the designed program for calculation of forcing spring stiffness as well as other computing programs for calculation of stiffness and shear stress of forcing springs.

2 SPRINGS

The springs are machine components which under loading are considerably deformed (see Fig. 1). Returning back to the initial state the springs derive the acquired deformation energy completely or at least partially. The springs are made from diverse materials and structured according to the conditions under which they are applied in technical practice. The mechanical devices employ the springs of diverse shapes and sizes. The springs are used in realization of flexible joints. When being deflected from the equilibrium position the connected components are exposed to effects of restoring force or spring momentum. To achieve definiteness of relative movement of the connected parts the spring joints are frequently combined with movable joints.

2.1 Cylindrical Helical Springs

With Circular Section of a Wire

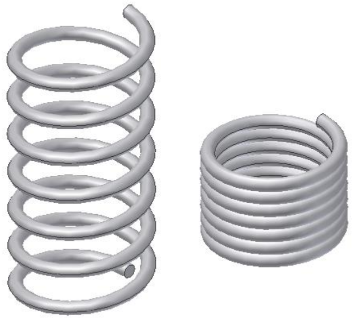


Figure 1. Free and maximally compressed forcing spring with circular section

In connection of two components it is stressed by compressive force (Fig. 2).

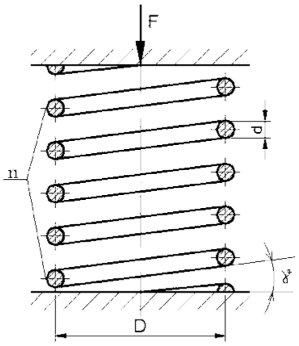


Figure 2. Spring stressed by compressive force

Approximate calculation is based just on taking into consideration stress of the spring wire by torsion

$$M_k = F\frac{D}{2}, \tag{1}$$

Consequently stress in torsion from M_k is defined by the following relation

$$\tau_k = \frac{M_k}{W_k} = \frac{F\frac{D}{2}}{\frac{\pi}{16}d^3} = \frac{8FD}{\pi d^3} \tag{2}$$

Stress along the spring section is not distributed evenly. Due to bending and curvature of the wire maximal stress occurs in the internal part of the section and the minimal one can be observed in the external part [Salokyova 2016b]. The calculation requires taking into consideration higher stress which is for circular section expressed by correction coefficient of q_1 and its value was determined experimentally by the following expression

$$q_1 = \frac{(i+0{,}25)}{(i-1)} + \frac{0{,}615}{i} \quad \text{with} \quad i = \frac{D}{d} \tag{3}$$

and then maximal stress in the spring wire is as follows

$$\tau_{k\max} = q_1 r = q_1 \frac{8FD}{\pi d^3} \tag{4}$$

Determination of Spring Stiffness on the Basis of Structural Parameters

To determine stiffness on the basis of structural parameters of the spring the linearity premise is stemmed from so in compressing the spring by force F_1 to value y_1 performed is the action A_1 with magnitude of

$$A_1 = \int_0^{y_1} F dy = c \int_0^{y_1} y dy = \frac{1}{2} F_1 y_1 \tag{5}$$

Deformation energy in twisting of the wire in the area of active threads reaching the amount of n can be expressed by the following expression

$$E_1 = \int_0^{\varphi_1} M_{k1} d\varphi \tag{6}$$

and in case of winding the elementary spring wire length " dl " the following is applicable

$$d\varphi = \frac{M_k}{G.I_p}.dl \quad . \tag{7}$$

When external action equals to internal energy (and when internal friction in material is neglected), i.e. $A_1 = E_1$, then with regards to the entire thread length the deformation action *"A"* is as follows

$$A = \frac{1}{2}\int_0^l \frac{M_k^2}{GI_p} dl = \frac{1}{2}\left(F\frac{D}{2}\right)^2 \frac{l}{G\frac{\pi}{32}d^4} = 4\frac{F^2D^3n}{Gd^4} \tag{8}$$

with

G - module of elasticity of shear,

I_p - polar moment of section inertia,

n – number of active threads,

l – wire length $l = n\pi D$ [Mascenik 2012]

For the spring compression the following is applicable

$$y = \frac{\partial A}{\partial F} = \frac{8FD^3 n}{Gd^4} = F\delta \tag{9}$$

with $\delta = \dfrac{8D^3 n}{Gd^4}$ - flexibility of the spring (10)

$k = \dfrac{1}{\delta} = \dfrac{Gd^4}{8D^3 n}$ - stiffness of the spring, (11)

Maximal shear stress is expressed by sum of stress from M_k and from shear force

$$\tau_{max} = \tau_1 + \tau_2 \tag{12}$$

with $\tau_1 = \tau_{k\max}$

and shear stress in the section of the spring wire from shear force

$$\tau_2 = \frac{4F}{\pi d^2} \tag{13}$$

Stability of the spring against deflection

$$\frac{y}{h} \le 0{,}83\left[1 - \sqrt{1 - 27\left(\frac{D}{h}\right)^2}\right] \tag{14}$$

The $\dfrac{D}{h} \rangle \dfrac{1}{5{,}25}$ is applicable – to prevent deflection of the spring yet it also depends on fixation of the spring ends in case of which h refers to the height of the uncompressed spring. Deflection can be prevented by conducting the spring is conducted in a sleeve or by an arbor [Mascenik 2016a].

Design Proposal of the Spring Dimensions

In design proposal of the dimensions of the compression helically wound spring a working diagram is stemmed from which constitutes the respective segment of the loading characteristics and that is determined by required working forces and by spring deformation according to Fig. 3.

Stiffness of the spring $k = \dfrac{F_8 - F_1}{h}$, (15)

with h – working stroke of the spring, $h = y_8 - y_1$ or $h = l_1 - l_8$.

Force F_9 refers to a maximal force in case of which a zero clearance occurs among threads.

Free length of the spring.

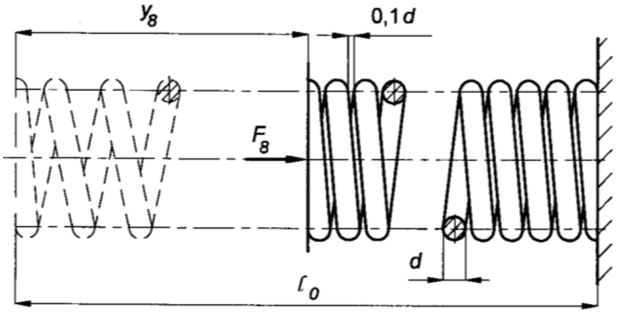


Figure 3. Free length of cylindrical spring with circular section of the wire

The length l_0 of unstressed spring, which contains both active and locking thread, is determined on the basis of requirement of the clearance with value of $0.1d$ among active threads under maximal stress produces by force F_8 (Fig 3). The following is thus applicable:

$$l_0 = y_8 + 0.1d \cdot n + d \cdot n + d \cdot n_z$$

(16)

with n_z referring to number of locking threads.

Inherent Frequency

In case of dynamically loaded compression springs it is inevitable to check prevention of occurrence of resonance oscillations under demanding operation conditions. Should the actuation frequency determined by dynamic load approximate the lowest inherent frequency of the spring oscillating, considerable increase of stress may occur due to inertial effects of a spontaneously oscillating wire of the spring with nominal weight of ρ [Mascenik 2016b]. It is inevitable to assure sufficient difference between the lowest inherent frequency

$$\omega_k = \frac{d}{nD^2}\sqrt{\frac{G}{2\rho}} \tag{17}$$

and the actuation one [Bicejova 2016b].

With Rectangular Section of the Wire

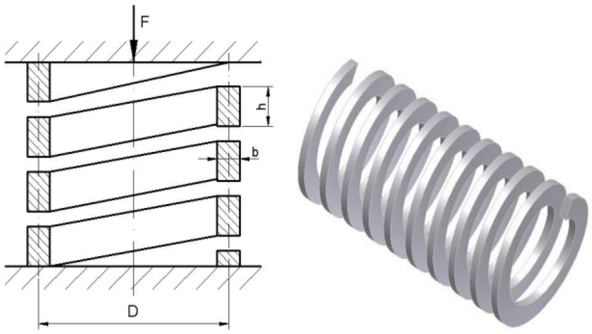


Figure 4. Compression spring with rectangular section of the wire

The spring shown in the Figure 4 disposes of linear loading characteristics. Design and strength checks are performed analogously to checks performed in case of the cylindrical spring with circular section of the wire with taking into consideration the rectangular section of the wire and spring geometry [Bicejova 2013a].

Maximal tension in torsion of the wire section

$$\tau_{max} = q_2 . \tau_k \tag{18}$$

Stress in torsion from axial stressing of the spring by force *F* is as follows

$$\tau_k = \frac{M_k}{W_k} \tag{19}$$

in case of which the torque stressing the wire section is as follows

$$M_k = F . \frac{D}{2} \tag{20}$$

Section module in torsion

$$W_k = \eta_1 . h^2 . b \, , \tag{21}$$

with η_1 - coefficient dependent on ratio of dimensions of the wire section

$$\eta_1 = f . \left(\frac{b}{h} \right) , \tag{22}$$

q_2 - refers to the correction factor taking into consideration the increase of stress in the thread of the spring in dependence on diameter of the spring *D* and dimensions of the wire section *h,b*

$$q_2 = f \left(\frac{D}{h} , \frac{D}{b} \right) . \tag{23}$$

Compression of the spring *"y"* in dependence on load produced by force *"F"* can be determined from geometrical characteristics of the spring as in case of the cylindrical spring with circular section by means of deformation action *"A"*.

then $y = \dfrac{\partial A}{\partial F}$

after derivation $$y = \gamma . \frac{F . D^3 . n}{b^2 . h^2 . G} = F . \delta \tag{24}$$

with flexibility $$\delta = \frac{\gamma . D^3 n}{b^2 . h^2 . G} \tag{25}$$

and with stiffness $$k = \frac{1}{\delta} = \frac{b^2 . h^2 . G}{\gamma . D^3 . n} \tag{26}$$

Coefficient γ represents the function of the relation $\dfrac{b}{h}$

$$\gamma = f \left(\frac{b}{h} \right) . \tag{27}$$

Coefficients q_2 , η_1 , γ - must be read off the graphs from the respective literature, e.g.

2.2 Conic Helical Springs

With Circular Section of the wire

The spring is produced from the wire with circular section and with diameter *d* which is wound around the conic area given by radius *R₁* and *R₂* with constant or variable angle of inclination of a medium helix (Fig. 5).

Significance of conic shape falls within the range of possibilities to reach non-linear characteristics of load due to gradual bearing of active threads on each other or onto a plate or within the range of possibilities of low block height that can be reduced to diameter of wire *d* [Puskar 2013].

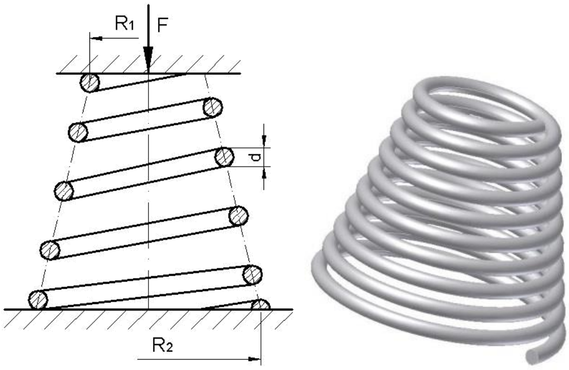


Figure 5. Conic helical spring with circular section of the wire

At random point from the beginning of the spring in turning by angle of α the radius of winding is can be expressed as follows

$$R = R_1 + \frac{R_2 - R_1}{2\pi n} \alpha \tag{28}$$

M_k - at random point

$M_k = FR$, resp. Maximal $M_{k\,max} = FR_2$ (29)

$$\tau_{max} = q_1 \tau_k$$

after substitution $$\tau_{max} = q_1 \frac{16 F R_2}{\pi d^3} \tag{30}$$

Compression of the spring *"y"* after substitutions $\left(y = \dfrac{\partial A}{\partial F} \right)$ is expressed as follows:

$$y = \frac{16}{\pi} . \frac{l \left(R_1^2 + R_2^2 \right)}{d^4} . \frac{F}{G} \tag{31}$$

length of spring wire

$$l = 2\pi n \frac{R_1 + R_2}{2} = \pi n \left(R_1 + R_2 \right) . \tag{32}$$

The expression for compression of the spring *"y"* is applicable just for the magnitude of force *F* , in case of which bearing of the active threads on each other is absent as well as their outage from springing. The non-linearity of the spring can be influenced by continual change of the wire diameter and through the inclination change of the spring helix.

With the Rectangular Section of the Wire

Stress of the wire from torque M_k is expressed as follows:

$$\tau = \frac{M_k}{W_k} \text{ maximal stress } \tau_{\max} = \frac{M_{k\max}}{W_k}.q_2 \qquad (33)$$

In case of rectangular section of the wire the coefficients η_1 and η_2, e.g., are implemented to determine both the polar moment of inertia I_p and the modulus of section in torsion W_k. Correction coefficient q_2, see the graph from the literature, e.g. [Halko 2013]

$$I_P = \eta_2.h.b^3, \quad W_K = \eta_1.b.h^2 \qquad (34)$$

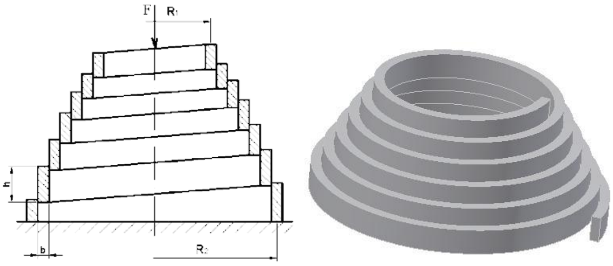


Figure 6. Wound helical spring

In case the threads are in contact, solid friction occurs between them. If the spring is wound as in Fig. 6, damping action can be observed (wagon buffers) [Krenicky 2008, Bicejova 2016b,c].
Deformation action

$$A = F\frac{y}{2} = \frac{F^2 l.(R_1^2 + R_2^2)}{4GI_p} \qquad (35)$$

In calculation of the spring deformation analogous conditions are applicable as in case of the conic spring with circular section of the wire with respecting the loading structure and geometry of the particular spring [Murcinkova 2013].

3 DESIGN OF A PROGRAM FOR CALCULATION OF STIFFNESS AND SHEAR STRESS OF FORCING SPRINGS

The given part of the paper analyses design of the generated computing program. The designed computing program was generated in Microsoft Office with the Excel application. The program generation consists of five basic steps:

1. Basic adjustments.
2. Generation of the first page of program.
3. Generation of a button.
4. Macro record [Bicejova 2013b].

3.1 Basic Adjustments

Prior to programming in the application of Microsoft Office Excel it is inevitable to carry out a basic adjustment consisting of two steps as follows:

1. Display the Developer tab.
2. Macro adjustment.

3.2 Generation of the First Page of the Program

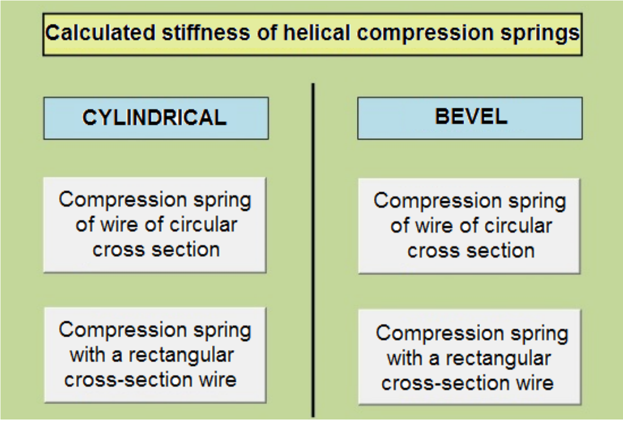
The designed program calculates the shear stress in torsion τ_k and stiffness of the forcing spring. The first page of program contains the program name in upper part (see Fig. 7). Furthermore, there is categorization of forcing springs into Cylindrical and Conic ones. Two buttons are assigned to the categorization. The first button serves for the springs with circular section of the wire and the second button serves for the springs with rectangular section of the wire [Smeringaiova 2016].

3.3 Generation of the Button

To start the macro up four buttons were generated on the first page. The buttons were generated on the Developer tab. When the tab is started up, the Developer offers the Controls of a Form and the ActiveX controls in the group of Controls. The button (Fig.7) was selected out of the group Controls of a Form. The placement of the button onto a working sheet into required position was performed by clicking to the working sheet location [Gaspar 2013].

3.4 Macro Record

The design and generation of the program was elaborated by Macro in the program of the Microsoft Office Excel pack. Macro can be employed in automation of frequently repeated tasks. In the Developer tab in the tool strip the macro can be generated by means of two methods. The first method refers to rapid macro record through macro record start-up. The second method refers to generation of the macro by means of the editor of Visual Basic and writing own macros script in the language of Microsoft Visual Basic. At the same time the entire macro or just its part can be copied into a new macro. When the macro has been generated, it might be assigned to a particular object (for instance, the button on the tool panel, graphics or controls) so that the clicking on the object is followed by macro start-up [Bicejova 2013].



Calculated stiffness of helical compression springs

CYLINDRICAL

BEVEL

Compression spring of wire of circular cross section

Compression spring of wire of circular cross section

Compression spring with a rectangular cross-section wire

Compression spring with a rectangular cross-section wire

Figure 7. Main window of a newly designed program

4 CONCLUSIONS

Nowadays the computer technology occupies a significant position in any sphere of human activity. Considerably high importance and frequent application of computer technology can be observed in the field of mechanical engineering along with the employment of diverse computing programs which help user get promptly oriented in the database of standardized mechanical parts and consequently calculate inevitable data and opt for the most suitable alternative.

The paper has presented the generated computing program for calculation of stiffness and shear stress of forcing springs. The computing program was verified in case of particular application example and compared with the calculation in the program of Autodesk Inventor Professional. The outputs of application example from both programs coincided which proved the correctness of functioning of the designed computing program generated in the Excel application.

The program is intended for standard mechanical practice and contains the calculations and tools which a mechanical engineer usually comes across. In case of a need the program results can be saved in the Excel file or printed. Currently, the market offers the programs for calculation of forcing springs such as TDS-TECHNIK, Mechsoft, MITCalc, Strojar, etc., which are, however, rather costly. The computing program was generated by the Excel application included in the Microsoft Office pack, i.e. this computing program is not investment-intensive and absent are high demands as to design and generation process. The program is a representative of far cheaper program alternative which efforts to achieve the Professional level of the aforementioned Professional products. The given program can be constantly under extension, i.e. it can be extended by diverse calculations and thus can save time and facilitate the work for the user. The advantage of the program stems in all formulae or texts being visible and controllable (other softwares possess major disadvantage – the man cannot see the core of the program [Mascenik 2016b]. They might see only the brackets, the texts, the numbers or a slash without any possibility of control). The man can see the very formula instead of unknown and incomprehensible lines. The respective program is easily controlled and uncomplicated as to operation (the user does not have to have knowledge from the field of programming languages of higher versions) and provides the user with fast and correct outputs.

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CONTACTS

Prof. M.Sc. Slavko Pavlenko, CSc.
Technical Universtity of Kosice
Faculty of Manufacturing Technologies with a seat in Presov
Department of Technical Systems Design
Bayerova 1, Presov, 080 01, Slovak Republic
+421 51 772 6466, slavko.pavlenko@tuke.sk, www.tuke.sk