WIRE DIAMETER OF HELICAL COMPRESSION SPRINGS INITIAL ESTIMATION

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Abstract
The article is focused on helical compression spring wire diameter estimation when the diameter is not specified or required. Formulae for initial estimation of minimal and maximal wire diameter based on amount and type of load and material properties were determined. Thus the diameter can be chosen from appropriate range.

Key words: helical spring, wire diameter; ultimate stress; spring index.

INTRODUCTION

In calculation process of helical compression springs the wire diameter is often fixedly given or estimated by guesswork or by experience (SCHMID, HAMROCK & JACOBSON, 2014; BUDYNAS & NISBETT, 2011). However, sometimes only load and deflection in selected spring positions are required and other dimensions of the spring including wire diameter are not defined. Whereby wire diameter is fundamental value for further calculation. It is useful to have some range of values for correct initial diameter estimation (ZACHARIÁŠ, 2002). Unfortunately, many of materials\` mechanical properties vary with wire size what makes the estimation difficult. Aim of this article was to provide method for appropriate estimation of wire diameter based only on amount and type of load and spring material properties.

MATERIALS AND METHODS

Maximal operational tangential stress in helical compression spring can be calculated by Equation (1) (SCHMID, HAMROCK & JACOBSON, 2014; BUDYNAS & NISBETT, 2011; ZACHARIÁŠ, 2002).

$$\tau = \frac{8 \cdot F \cdot D}{\pi \cdot d^3} \cdot K \qquad (1)$$

where *F* is maximal operational loading force in *N*, *D* is mean coil diameter in *m*, *d* is wire diameter in *m* and *K* is stress correction factor. There are more correction factors used around the globe. In this case Wahl's factor was used (SUHU, KUMAR & KUMAR, 2014). It can be determined by Equation (2) (WAHL, 1944). For easier evaluation several replacements for Wahl's factor are used. Equation (3) (ZACHARIÁŠ, 2002) was used in presented calculation.

$$K = \frac{4C-1}{4C-4} + \frac{0.615}{C} \qquad (2)$$

$$K = 1 + \frac{1.53}{C} \qquad (3)$$

where *C* is spring index which is calculated by Equation (4).

$$C = \frac{D}{d} \qquad (4)$$

Different spring index ranges are recommended in the literature although they cover similar values, e.g. *4-12* (SCHMID, HAMROCK & JACOBSON, 2014; BUDYNAS & NISBETT, 2011) or *5-15* (ZACHARIÁŠ, 2002; SUHU, KUMAR & KUMAR, 2014). Values lower than the range are considered hard to manufacture and inclinable to fatigue. Higher values bring inconstant coil diameter, flimsiness and the springs more likely tangle when manipulated or transported.

Furthermore, the allowable shear stress is needed for the calculation. Generally, the tensile strength of the material is the value that is provided by manufacturer or by the standard. It is related to wire diameter and also the material processing. Its relation to wire diameter can be described by Equation (5) (SCHMID, HAMROCK & JACOBSON, 2014; BUDYNAS & NISBETT, 2011).

$$\sigma_{ut} = \frac{A_s}{d^{m_s}} \qquad (5)$$

Where: A_s is constant in $MPa \cdot mm^{ms}$, *d* is wire diameter in *mm* and m_s is exponent.

These values are obtained by mechanical tests, they are valid for specific range of diameters and they can vary by different manufacturers or different literature. Obviously, the variation for standard materials should be minimal. E.g. the published values for Chrome-Silicon wire are $A_s = 1974\ MPa \cdot mm^{0.108}$ and $m_s = 0.108$ (valid for d = 1.6-9.5 mm) (Budynas & Nisbett, 2011) or $A_s = 2000\ MPa \cdot mm^{0.112}$ and

$m_s = 0.112$ (valid for d = 1.6-10 mm) (SCHMID, HAMROCK & JACOBSON, 2014). The relation between allowable shear stress and tensile strength of the material is also dependent on material and its processing. The correlation factor k_{all} values (ranges) are also slightly different across different sources and the correlation can be expressed by Equation (6).

$$\tau_{all} = k_{all} \cdot \sigma_{ut} \tag{6}$$

Maximal operational stress of the string must be lower than allowed shear stress, thus there must be a reserve for full string deflection – Eq. (7) (ZACHARIÁŠ, 2002).

$$\tau = k_d \cdot \tau_{all} \tag{7}$$

where □$_{all}$ is allowed shear stress and k_d is reserve factor.

By substitution Equations (3) to (7) into Eq. (1) full equation for maximal operational shear stress of the spring is derived. After evaluation the formula for wire diameter is obtained – Eq. (8).

$$d = \left[\frac{8 \cdot F}{\pi \cdot k_{all} \cdot k_d \cdot A_s} (C + 1.53) \right] \tag{8}$$

For wire diameter estimation range determination it is necessary to substitute appropriately minimal and maximal values for all constants that have ranges. Then the Equations (9) and (10) are obtained.

$$d_{\min} = \left[\frac{8 \cdot F}{\pi \cdot k_{all\max} \cdot k_{d\max} \cdot A_s} (C_{\min} + 1.53) \right]^{\frac{1}{2-m_s}} \tag{9}$$

$$d_{\max} = \left[\frac{8 \cdot F}{\pi \cdot k_{all\min} \cdot k_{d\min} \cdot A_s} (C_{\max} + 1.53) \right]^{\frac{1}{2-m_s}} \tag{10}$$

RESULTS AND DISCUSSION

Based on Equations (9) and (10) the final formulae for wire diameter estimation are derived – Eq. (11), (12) and (13).

$$d = (B_{s\min} \div B_{s\max}) \cdot F^{\frac{1}{2-m_s}} \tag{11}$$

$$B_{s\min} = \left[\frac{8 \cdot (C_{\min} + 1.53)}{\pi \cdot k_{all\max} \cdot k_{d\max} \cdot A_s} \right]^{\frac{1}{2-m_s}} \tag{12}$$

$$B_{s\max} = \left[\frac{8 \cdot (C_{\max} + 1.53)}{\pi \cdot k_{all\min} \cdot k_{d\min} \cdot A_s} \right]^{\frac{1}{2-m_s}} \tag{13}$$

where B_{min} and B_{max} are constants of diameter estimation range.

Constants values used for calculation can be obtained by any appropriate source. For illustration of described process selected values are shown in Tab. 1. The column *d* limits the validity of further constants.

For comfortable or repeated calculation the Tab. 1 could be enlarged by column B_s which represents the range of diameter choice – Tab. 2.

Example of calculation follows.

Input values:

Loading force F = 2000 N

Static load

Wire material – Chrome-Silicon

A_s = 1974 MPa · mm$^{0.108}$; m_s = 0.108; C_{min} = 4;
C_{max} = 12; k_{allmin} = 0.65; k_{allmax} = 0.75; k_{dmin} = 0.84;
k_{dmax} = 0.94

Result values:

$$d = (0.088 \div 0.162) \cdot F^{\frac{1}{2-0.108}}$$

Thus wire diameter should be chosen from range:

$$d = 4.9 \div 9.0 mm$$

This range has to be compared to range of validity from *Tab. 1* and the final diameter must fit in both ranges. In this example, any available diameter from given range can be chosen and it is highly probable that it will not be necessary to change it afterwards due to strength check failure or other requirements miss.

Presented method allows the designer to choose the wire diameter from appropriate range based only on amount and type of load and selected material properties (ZACHARIÁŠ, 2002). It is different from generally used trial selection of wire diameter (SCHMID, HAMROCK & JACOBSON, 2014; BUDYNAS & NISBETT, 2011). There is also possibility to choose acceptable string index and calculate approximate wire diameter which is rounded to nearest available value (BUDYNAS & NISBETT, 2011).

Values for quick calculation based on selected information sources were provided (Tab. 1 and Tab. 2) so it is possible to use this article for spring design immediately. If different material properties, acceptable spring index range or safety factor is used, the method for obtaining custom constants was provided – Equations (11), (12) and (13).

Tab. 1. – Constants values for selected spring wire materials (BUDYNAS & NISBETT, 2011; ZACHARIÁŠ, 2002)

Material	d	A_s	m_s	C	k_{all}	k_d
	mm	$MPa \cdot mm^{ms}$	-	-	-	-
Music wire	0.1-6.5	2211	0.145	4-12	0.45-0.60	0.84-0.94
Oil-tempered wire	0.5-12.7	1855	0.187	4-12	0.45-0.50	0.84-0.94
Hard-drawn wire	0.7-12.7	1783	0.190	4-12	0.45-0.55	0.84-0.94
Chrome-Vanadium wire	0.8-11.1	2005	0.168	4-12	0.65-0.75	0.84-0.94
Chrome-Silicon wire	1.6-9.5	1974	0.108	4-12	0.65-0.75	0.84-0.94
302 Stainless steel	0.3-2.5	1867	0.146	4-12	0.45-0.55	0.84-0.94
	2.5-5.0	2065	0.263	4-12	0.45-0.55	0.84-0.94
	5.0-10.0	2911	0.478	4-12	0.45-0.55	0.84-0.94
Phosphor-bronze	0.1-0.6	1000	0.000	4-12	0.45-0.50	0.84-0.94
	0.6-2.0	913	0.028	4-12	0.45-0.50	0.84-0.94
	2.0-7.5	932	0.064	4-12	0.45-0.50	0.84-0.94

Tab. 2. – Wire diameter range values for selected spring wire materials

Material	d	B_s
	mm	$mm \cdot N^{-1/(2-ms)}$
Music wire	0.1-6.5	0.089-0.179
Oil-tempered wire	0.5-12.7	0.103-0.190
Hard-drawn wire	0.7-12.7	0.099-0.193
Chrome-Vanadium wire	0.8-11.1	0.081-0.151
Chrome-Silicon wire	1.6-9.5	0.088-0.162
302 Stainless steel	0.3-2.5	0.102-0.196
	2.5-5.0	0.083-0.166
	5.0-10.0	0.046-0.103
Phosphor-bronze	0.1-0.6	0.173-0.302
	0.6-2.0	0.177-0.311
	2.0-7.5	0.169-0.301

CONCLUSIONS

Universal method for appropriate estimation of wire diameter of helical compression spring was determined. The estimation can be based only on amount and type of load and selected wire material. This procedure can be useful when only force and deflection of spring are specified.

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