Stock Spring Selection Tool

Introducing an algorithm that performs all necessary calculations to find the most suitable stock spring from a catalog, directly using designer specifications

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This article describes a new algorithm for choosing the best spring from within a database, which users could easily implement online. The algorithm performs all necessary calculations to propose the most suitable stock spring from a catalog, directly using the designer specifications. It enables specification sheet data defined with interval values for use in the first steps of the design cycle. This type of specification fits perfectly with the designer's incomplete knowledge in the early design stages. This article offers two examples using a spring manufacturer's database, which comprises more than 5,000 references.

1 Introduction

The creation of mechanical objects is often the end result of a long design process. Designers are always under pressure to reduce the time cost, whereas the knowledge doesn't stop increasing. Standard component selection is perhaps the simplest, but nonetheless an important, class of design decision problems. Catalogs are increasingly common and voluminous. Thus a strong link between designers and component manufacturers is essential to automate catalog search.

Design engineers often face the problem of including stock springs. It's interesting to analyze the method used to select stock springs. The following highlights the difficulties encountered, the help available today and what could be added to ameliorate it.

The usual method for selecting stock springs can be divided in three steps:

Step 1: Evaluate, from the requirements, some spring design parameters listed in the catalog of the chosen spring manufacturer.

Step 2: Find springs according to these parameters' values.

Step 3: Calculate the working parameters for each spring found in order to select one that satisfies the specification.

Thus, the designer is confronted with the following problem: On the one hand, when the specification is imprecise, there is a big range of springs available, and it is not easy to find the best one. On the other hand, when the specification is precise, there is a small range of springs available, and it becomes very difficult to find one of them in a catalog.

To improve the spring selection, University of Missouri professor Yuji Lin and his associates (3) developed an expert system to simplify the first two steps of the stock spring selection process. Step 3, with its many calculations, still had to be performed by the designer.

Technical literature provides mathematical methods which, in every case, calculate design parameters corresponding to an optimal design (Sandgren (5), Kannan and Kramer (4), Deb and Goyal, (2)). Designers could use these

Nomenclature

- \( D_o \): outside diameter in mm
- \( D \): mean diameter in mm
- \( D_i \): inside diameter in mm
- \( d \): wire diameter in mm
- \( R \): spring rate in \( \text{N/mm} \)
- \( L_0 \): free length in mm
- \( n \): number of active coils
- \( \gamma \): helix angle in degrees
- \( p \): pitch of the spring in mm
- \( P_1, P_2 \): spring load in N
- \( L_1, L_2 \): spring length in mm
- \( \delta \): spring travel in mm, \( \delta = L_1 - L_2 \)
- \( \tau_m \): mean stress in \( \text{N/mm}^2 \)
- \( \tau_a \): alternate stress in \( \text{N/mm}^2 \)
- \( K_s \): stress correction factor (Walt, 1963)
- \( \text{UTS} \): ultimate tensile strength of the material in \( \text{N/mm}^2 \)

Subscripts
- \( S \): from the specification sheet

Superscripts
- \( U \): upper limit
- \( L \): lower limit
methods in Step 1, but problems have been simplified and the practical existence of the spring is never envisaged.

To our knowledge, the following capabilities are not usually presented:
1. Suggesting the most suitable spring from a database.
2. Taking uncertain working parameters into consideration (data set with interval values).
3. Performing all the necessary calculations, such as buckling and fatigue life, to verify that a spring satisfies the specification.

One would expect catalog search software tools to perform all necessary calculations and manage uncertain parameters. This has not been the case.

This paper, however, proposes a new approach that could be used even in the early design stages. To fit perfectly with the designer's incomplete knowledge, the method determines springs for a specification sheet where data can be uncertain. The associated algorithm first establishes, from a manufacturer's database, which springs satisfy the requirements. Then it selects the best one, calculating the working parameters for a given objective. Using this kind of tool, the designer only has to input his specification sheet.

The present study deals only with helical compression springs with closed ends, and with closed and ground ends.

2 Definitions

2.1 Design parameters of a spring

The parameters defining spring geometry are $D_o$, $D$, $D_1$, $d$, $R$, $I$, $N$, $n$, $z$, and $V$, Figure 1, left, illustrates these parameters, which characterize the intrinsic properties of the spring. Four independent parameters must be known to calculate the six others.

2.2 Working parameters of a spring

Traditionally, a spring works between two configurations, one corresponding to the least compressed state, $W_1$; the other corresponding to the most compressed state, $W_2$. Thus the parameters that define the use of a spring are $P_1$, $P_2$, $L_1$, $L_2$ and $sh$ (see Figure 2, left). When the design parameters are known, only two independent working parameters (to be taken among $P_1$, $P_2$, $L_1$, $L_2$ and $sh$) are necessary to determine the two working points, $W_1$ and $W_2$.

2.3 Specification sheet

In the early stage of a design, there are always many parameters that have not yet been fixed. Thus it is difficult to give fixed values for a spring, and it is more convenient to define parameters through possible lower and upper limits. That's why the proposed specification sheet is defined with interval values, as shown in Figure 3, left. The designer indicates design and working parameters by giving their bounds (lower/upper limits: $L_1^{[l]}$, $L_1^{[u]}$, $P_1^{[l]}$, $P_1^{[u]}$, ..., $L_2^{[l]}$, $L_2^{[u]}$, $P_2^{[l]}$, $P_2^{[u]}$, ..., $sh^{[l]}$, $sh^{[u]}$). Each fixed parameter simply involves the specification of lower limit equal to upper limit.
Moreover, the designer can define a number of other characteristics with interval values:
- Natural Frequency of surge waves
- Spring mass
- Overall space taken up when uncompress (L−L0)
- Overall space taken up when compressed (L−L2)
- Internal energy during the working travel

Designers can provide additional data to calculate other characteristics:
- Number of cycles (Nc) to calculate fatigue life factor (to check that it is higher than unity)
- End fixation factor (V) to calculate the buckling length (Ll) and check that it is less than L2.

The designer can also specify the material and spring ends required.

Finally, to calculate the best spring, designers must input the objective function, such as "maximize fatigue life," "minimize mass," or "minimize L2."

2.4 Database

The database contains all of the stock springs offered by the manufacturer. Each spring is characterized by four design parameters: the end type (closed and grounded, or closed and not grounded); and the spring material (steel or stainless).

3 Finding the most suitable spring in a manufacturer catalog

Designers could apply general methods dedicated to component selection problems, such as the one proposed.

Figure 4: Catalog search algorithm. The algorithm's initial task is to find the whole range of springs that fit the specification sheet. With this intention, it tests all springs, one by one, and only retains those that are appropriate. It then classifies according to the objective function chosen by the designer.

Figure 5: Uncertain working parameters
by Bradley and Agogino (1), to the stock spring selection problem. However, they could obtain significant reduction in development costs and processing times using a more direct method that takes advantage of the spring problem characteristics. The following method was conceived with this aim. Figure 4, page 55, illustrates the algorithm used.

The algorithm’s initial task is to find the whole range of springs that fit the specification sheet. With this intention, it tests all springs, one by one; and only retains those that are appropriate. It then classifies according to the objective function chosen by the designer. Let us see now how to determine whether a spring in the base is available.

### 3.1 Dealing with design parameters

The algorithm compares spring characteristics given in the catalog — usually Do, d, LO and R — to the specification. Next, it calculates other properties of the spring related to the design parameters — such as D, Df, Ls, mass, overall space taken up when uncompensated and natural frequency — and compared to the specification. Formulas used in these calculations are shown in Appendix 1, page 63. Then, it carries out a second selection, which is based on the characteristics related to the working parameters. Here is how the second stage is carried out:

### 3.2 Dealing with working parameters

#### 3.2.1 First without fatigue life verification

First, ignoring the fatigue life requirements, the algorithm analyzes the specification to determine if there is a possible use of each pre-selected spring.

This use is characterized by the two points in question W1 and W2 (see Figure 2, page 54). In this study, these points will be defined by their respective x coordinates — L1 and L2.

All specification sheet values can be set with intervals, thus L1 and L2 are bounded by an upper limit and a lower limit that can be different from those of the specification (L1, L1' and L2, L2': see Figure 5, page 55).

L1 and L2 limits are calculated by the most reducing limits of the working parameters:

\[ L1' = \text{Min}(L1', \ LO - P1_2 R) \]  \hspace{1cm} (1)

\[ L1 = \text{Max}(L1, \ LO - P1_2 R) \]  \hspace{1cm} (2)

\[ L2' = \text{Min}(L2', \ LO - P2_2 R) \]  \hspace{1cm} (3)

\[ L2 = \text{Max}(L2, \ LO - P2_2 R) \]  \hspace{1cm} (4)

By considering the practical application of the process, it is important not to forget in the calculation of L2 the spring buckling (Lf) according to the end fixation factor (SMI) and minimum allowable working length (Ln):

\[ L2^L = \text{Max}(L2^L, \ LO - P2_2 R, Lf, Ln) \]  \hspace{1cm} (5)

In the same way, a specification on the internal energy of the spring involves conditions on the spring travel (the formulas are shown in appendix 1):

\[ sh^U = \text{Min}(sh^U, \ sqrt{2 \times \text{energy}^U / R}) \]  \hspace{1cm} (6)

\[ sh^L = \text{Max}(sh^L, \ sqrt{2 \times \text{energy}^L / R}) \]  \hspace{1cm} (7)

If the calculation leads to \(L1' > L1; L2' > L2; sh^U > sh^L; \ L1' - L2 > sh^U; \ L1 - L2 < sh^L\), then the selected spring is rejected.

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**Figure 6 Solution area for L1 and L2**

**Figure 7 L1 and L2 for maximum fatigue life**
If, on the contrary, there is an initial potentially acceptable operating range, fatigue life must be taken into account to check if the spring can be accepted.

3.2.2 Then dealing with fatigue life

To determine if the spring satisfies the fatigue life, the working parameters (L1 and L2) are calculated to obtain the maximum fatigue life factor while satisfying the specification. If the value of the obtained fatigue life factor is lower than 1, the studied spring is not appropriate. If 1 or greater, a solution area exists (see Figure 6, page 57), and the spring is retained as a potential candidate.

In general, this leads to an optimization with two variables, L1 and L2 (to fix the working parameters), to find the optimal point L1, L2 that gives the maximum fatigue life factor and satisfies the specification.

Figure 6 presents the feasible area for which the borders of the solution area are determined by all the constraint curves. (Note: Appendix 2 shows that the constraint limit related to fatigue life is a line of positive slope lower than unity.)

According to the objective of having the maximum allowable fatigue life factor, the algorithm determines the constraints likely to be active at the optimum. Then it indexes all the intersection points between these constraints, retaining only potential optimum points. For each possible optimum point, graphs of the corresponding constraints highlight their properties (see Figure 7, page 57).

Thus, the maximum shear stress is minimized, leading to the maximization of L2. Then the alternate stress is minimized, leading to the maximization of L1. The analysis of Figure 6 concludes by selecting the intersection point G1/G7, G4/G7 or G1/G3. The three cases are indexed in Figure 7, with the three intersection points represented by circles.

The algorithm retains points with minimum L2 values. When two points are still valid, as in Figure 7a and 7c, it only retains the one with maximum L1 value.

Then, it calculates the maximum fatigue life factor. If the obtained value is greater than 1, the studied spring is retained as a potential candidate.

Two different cases are developed hereafter to definitely choose L1 and L2. The first case is when the working points are selected so that the spring is the least stressed, which corresponds to the objective «maximize fatigue life». The second one deals with an objective function, such as «minimize L2».

3.3 Determining the optimal working points
3.3.1 Maximizing fatigue life

Section 3.2.2 discusses how the working points have been calculated to have the greatest fatigue life. This method is used as the default whenever the specified objective is independent of the working parameters, such as mass, natural frequency of surge waves and so on. Alternatively, the algorithm can determine the working points to meet the objective of minimizing L2 (the overall space taken up when compressed).

3.3.2 Minimizing L2 value

The minimum value of L2 is obtained with the same method used to maximize fatigue life. To minimize L2 value, L1 is implicitly minimized to have the lowest alternate stress. The choice lies among five distinct possibilities. These are indexed in Figure 8, below. The potential optimal points are represented by squares.

The point selected from among the five potential points is, in all cases, the one with the maximum values of L1 and L2.

3.4 Classifying the accepted springs according to the objective

After the confrontation step described above, the algorithm describes the whole range of springs within the

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**Fig. B.** L1 and L2 for minimum L2
corresponding specification sheet. For each spring, it has determined optimal values of L₁ and L₂. Next, it calculates the value of the objective function attained by the designer to classify the springs by order of decreasing interest.

Following are two examples in which this algorithm is used.

### 4 Examples

The following examples use the Reissert VANELL catalog, which includes 5050 springs. The calculation time on a personal computer (300Mhz) is less than one second for each example.

#### 4.1 Spring for a clamping pin

In this example, the goal is to obtain the spring with the smallest value of L₂.

**Specification sheet:** The maximum outside diameter of the spring is 38 mm, the minimum inside diameter is 27 mm, spring travel must be 11 mm, the load P₁ must be between 5 and 15 N, and P₂ between 50 and 100 N (see Figure 9, below, left).

**Result of research:** There are 25 springs that fit the given specification sheet (see Figure 10, below, left). According to the chosen objective, the algorithm calculates the working point of each available spring to have the minimum working length, L₂, satisfying the specifications. The optimal spring of the database is thus the first of the list, which is classified by increasing length L₂: D₀ = 32.0 mm, d = 2.2 mm, L₁ = 25 mm, R = 5.78 N/mm, L₁ = 22.4 mm, L₂ = 11.4 mm (steel with closed and ground ends).

#### 4.2 A spring for an axial pump

The second example is the optimal dimensioning of a piston drawback spring used in an axial pump. The objective is to find the spring offering the greatest fatigue life factor.

**Specification sheet:** The spring travel, sh, is constant (15 mm). The dynamic study of the system defines the maximum spring load P₂ (200 N) as well as the limit values of the spring rate R (4 and 10 N/mm). The spring must have a minimum life of 10⁷ cycles. To avoid any problem of wear due to friction, the spring should not buckle, and the supports

![Figure 9: Clamping pin](image)

![Figure 11: Pump piston](image)

![Figure 10: A stock spring for a clamping pin](image)

![Figure 12: A stock spring for a pump piston](image)
should be parallel and guided, which gives an end fixation factor of 0.5 (DIN standard). The imposed natural frequency is higher than twice the maximum frequency of the pump (25100 Hz). Finally, the compressed spring must be included in the piston (see Figure 11, page 63). Its outside diameter Do is lower than DM (22 mm), and L2 is lower than LM (64 mm).

Result of research: Only nine springs are appropriate for this application. From these, the best is selected (see Figure 12, page 63): Do = 22 mm, d = 2.8 mm, L0 = 89 mm, R = 7.56 N/mm (L1 = 48.55 mm, L2 = 52.55 mm). The chosen spring offers a fatigue life factor of 1.09 (steel with closed and ground ends).

5 Conclusion

Component selection is one of the most frequently encountered problems during the design process. Advanced tools dedicated to stock spring selection would increase links between spring manufacturers and design engineers.

The major advantage of the suggested algorithm is to include all the necessary calculations for selecting the most suitable stock spring. Thus, the user is sure the proposed spring satisfies his specification sheet.

The other interest of this approach is the ability to start from a specification allowing uncertain parameters. This is useful for design engineers. When a spring is sought from within a catalog, the specification can be built up in real-time. As long as there are a number of stock springs available, parameter bounds can be added or refined, and the new best spring can be reached interactively.

This approach could easily be extended to other springs (extension springs and torsion springs). Stock spring manufacturers could easily create their own software tools, based on this algorithm, to give to customers.

Acknowledgments

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References


6. Spring Manufacturers Institute, "Guidelines For Spring Testing," 2001 Midwest Road, Suite 106, Oak Brook, IL, 60523 USA.

Manuel Paradis is a mechanical engineer who used to work for the industry as a research engineer on ship rigging. He has been studying for his doctorate since 1997 at the Mechanical Engineering Laboratory of the National Institute of Applied Sciences of Toulouse (INSA). Marc Sartor is an associate professor at INSA. Jean-Christophe Faivre is an associate professor at IFMA.

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Appendix 1: Formulas

- The stock spring catalog used is defined by Do, d, L0 and R. Thus, the formulas used to define the other characteristics related to design parameters are:

\[ d = D_0 - d \]
\[ D_0 = D_0 - 2 \ell \]

\[ n = G/(8R D^p) \] with \( G \): torsion modulus of the material in N/mm²

\[ \rho = (1.5 - n) \tan, \text{ with } n = 2 \text{ for closed and } n = 3 \text{ for closed ends} \]

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![Figure 13: Hailsh Diagram](Image)
The helix angle must be lower than 7.5° so the calculations remain valid: ϵ = \arccos(\frac{\rho}{\sqrt{2\pi D d}})
(12)

Natural frequency of surge waves (in Hz):

$$f_r = \frac{\pi \times 10^{12}}{\sqrt{\rho^2 \pi D d^2}}$$

(13)

with \( \rho \) density of material in kg/m³

Spring mass (in g):

\[ M = \pi^2 \rho (n + 1.5) D d^2 / 4 \times 10^{-6} \]

(14)

Overall space taken up when uncompressed (in cm³):

\[ V_{oilL} = \frac{1}{3} \pi D d^2 / 4 \times 10^{-3} \]

(15)

* The characteristic related to working parameters defined using L₁ and L₂ are:

\[ P_1 = 4R \times [L_1 - L_1] \]

(16)

\[ P_2 = 4R \times [L_2 - L_2] \]

(17)

\[ h = L_1 - L_2 \]

(18)

Internal energy during the working travel (in N.mm):

\[ \text{Energy} = 0.5 \times R \times h \]

(19)

Overall space taken up when compressed (in cm³):

\[ Vol_{oilL} = L_2 \pi D d^2 / 4 \times 10^{-3} \]

(20)

Minimum working length (in mm) \( L_n = d(\text{in} + \text{n}) \cdot s_n \) with:

\[ s_{10} = a (0.0015 D d^2 + 0.14) \]

(21)

* It is also necessary to take into account, if required in the specification sheet, the constraint related to buckling according to the end fixation factor \( v \) (DIN 2089):

\[ \frac{\pi \times L_1}{L_0} \]

if \( \pi L_1 / L_0 > \frac{2 \mu + 1}{2 \mu + 2} \) then \( \pi L_1 / L_0 = 0 \) (there is no risk of buckling)

else \( \pi L_1 / L_0 = 1 + \frac{1}{\pi} \left( 1 - \frac{2 \mu + 1}{\pi L_1 / L_0} \right) \in \text{mm} \)

(22)

with \( \mu = \frac{E}{2G} - 1 \) and \( E \): elastic modulus of the material in N/mm².

The calculation of the fatigue life factor is described in Appendix 2, below.

**Appendix 2: The fatigue life curve is a line of positive slope lower than unity.**

In Figure 13, page 90, a fatigue diagram, the Fatigue Life Factor is the ratio between OW and OL.

\[ \text{Fatigue Life Factor} = \frac{S}{S_0} \]

(23)

with:

\[ S_1 = \left( \frac{0.9 UTN - \pi d_{SN}}{\pi d(0.9 UTN - \pi d_{SN})} \right) \times \pi d_{SN} \]

(24)

\[ S_2 = 0.45 UTN / (\pi d + 0.5m) \]

(25)

\[ \text{UTN} = 4DR (L_1 - L_2) \text{Kts} / (\pi d) \]

(26)

\[ \pi d_{SN} = 4DR (L_1 - L_2) \text{Kts} / (\pi d) \]

(27)

\[ \pi d_{SN} = \begin{cases} \pi d \text{ if } N_1 \geq 10^7 \text{ (fatigue limit)} \\ [\pi d - 0.45 UTN] / \ln N_1 / \ln(1 + 3.15 UTN - 4\pi d) / 3 \text{ if } 10^7 < N_1 < 10^{10} \\ 0.45 UTN \text{ if } N_1 \leq 10^7 \text{ (static limit)} \end{cases} \]

(28)

\[ L_2 = f(L_1) \] is calculated with a fixed \( aF \). Let us consider the first member of the calculation of \( aF \) (the second member is the static calculation) and set down:

\[ A = \pi d_{SN} (0.9 UTN - \pi d_{SN}) \]

(29)

\[ B = \frac{A}{\pi d_{SN}} \]

(30)

\[ C = \frac{4.1 \pi d_{SN}}{\pi d_{SN}} \]

(31)

There is \( aF - A / [B(P_1 + P_2) + C(P_1 + P_2)] \)

thus \( P_2 = A / [aF(B + C)] + P_1 \) (B) \( C \) \( V(B + C) \)

(32)

therefore

\[ R (L_1 - L_2) = \frac{\pi d_{SN} \text{ Kts}}{aF(B + C)} \]

(33)

from where:

\[ L_2 = \frac{A}{\pi d_{SN} R} + L_1 \frac{2B}{B + C} + L_1 \frac{B - C}{B + C} \]

(34)

however

\[ 0 < \frac{B - C}{B + C} = \frac{0.45 UTN - \pi d_{SN}}{0.45 UTN} \leq 1 \]

(35)

Thus the curve \( L_2 - (L_1) \) with a fixed \( aF \) is a line of positive slope lower than unity.

![For up-to-the-minute information on the Spring Manufacturers Institute and the North American precision mechanical spring industry, point your internet browser to: www.smihq.org](www.smihq.org)