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Selection of Spring Material Using PROMETHEE Method

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Abstract: *Like most other fundamental mechanical components which form the basis of many mechanical systems, springs have existed since the Bronze Age for storage or release of energy, absorption or utilization of vibration, relaxation or absorption of impact force and when unloaded, return to the original position or to the original shape. Quality, service requirement, performance as well as durability of springs greatly depend on the quality of materials used and manufacturing processes. So, spring material and its quality can normally be taken into consideration and consequently, material selection plays an important role during designing of a spring for a particular application. Common spring materials include stainless steel, alloy steels, carbon steels, non-ferrous materials and some super-alloys which exist in the market with preparatory designations and nomenclature. Each spring material has diverse compositions, individual properties and also for a particular type of spring, more than one feasible alternative spring materials may be available in the market. To avoid these complex conditions and consequently achieving the optimal spring design, it is exceptionally crucial to select the most suitable material with the desired properties for enhanced durability, low operational and manufacturing cost, and better performance of the spring. This paper considers a list of seven spring material alternatives whose performance is evaluated based on eight selection criteria. An integrated preference ranking organization method for enrichment evaluation (PROMETHEE II) and graphical analysis for interactive assistance (GAIA) technique is applied to solve this spring material selection problem, and a full ranking of the spring material alternatives with suitable graphical displays is presented. Chrome silicon alloy steel (ASTM A 401) is the best spring material, followed by high carbon steel (ASTM A 228) and Inconel 600. Monel K500 is the worst chosen spring material.*

Keywords : *PROMETHEE Method, Rockwell Hardness, spring, Tensile Strength, Modulus of Elasticity,*

I. INTRODUCTION

A coiled metal device that is able to store mechanical energy. It is an elastic object. A spring is a device that changes its shape in response to an external force, returning to its original shape when the force is removed. The energy expended in deforming the spring is stored in it and can be recovered when the spring returns to its original shape. Generally, the amount of the shape change is directly related to the amount of force exerted. If too large a force is applied, however, the spring will permanently deform and never return to its original shape.

There are several types of springs. One of the most common consists of wire wound into a cylindrical or conical shape. An extension spring is a coiled spring whose coils normally touch each other; as a force is applied to stretch the spring, the coils separate. In contrast, a compression spring is a coiled spring with space between successive coils; when a force is applied to shorten the spring, the coils are pushed closer together. A third type of coiled spring, called a torsion spring, is designed so the applied force twists the coil into a tighter spiral. Common examples of torsion springs are found in clipboards and butterfly hair clips. Still another variation of coiled springs is the watch spring, which is coiled into a flat spiral rather than a cylinder or cone. One end of the spring is at the center of the spiral, and the other is at its outer edge. Some springs are fashioned without coils. The most common example is the leaf spring, which is shaped like a shallow arch; it is commonly used for automobile suspension systems. Another type is a disc spring, a washer-like device that is shaped like a truncated cone. Open-core cylinders of solid, elastic material can also act as springs. Non-coil springs generally function as compression springs.

Very simple, non-coil springs have been used throughout history. Even a resilient tree branch can be used as a spring. More sophisticated spring devices date to the Bronze Age, when eyebrow tweezers were common in several cultures. During the third century B.C., Greek engineer Ctesibius of Alexandria developed a process for making "springy bronze" by increasing the proportion of tin in the copper alloy, casting the part, and hardening it with hammer blows. He attempted to use a combination of leaf springs to operate a military catapult, but they were not powerful enough. During the second century B.C., Philo of Byzantium, another catapult engineer, built a similar device, apparently with some success. Padlocks were widely used in the ancient Roman Empire, and at least one type used bowed metal leaves to keep the devices closed until the leaves were compressed with keys.

The next significant development in the history of springs came in the middle Ages. A power saw devised by Villard de Honnecourt about 1250 used a water wheel to push the saw blade in one direction, simultaneously bending a pole; as the pole returned to its unbent state; it pulled the saw blade in the opposite direction.

In the eighteenth century, the Industrial Revolution spurred the development of mass-production techniques for making springs. During the 1780s, British locksmith Joseph Bramah used a spring winding machine in his factory. Apparently an adaptation of a lathe, the machine carried a reel of wire in place of a cutting head. Wire from the reel was wrapped around a rod secured in the lathe. The speed of the lead screw, which carried the reel parallel to the spinning rod, could be adjusted to vary the spacing of the spring's coils. Common examples of current spring usage range from tiny coils that support keys on cellular phone touchpad to enormous coils that support entire buildings and protect them from earthquake vibration.

Steel alloys are the most commonly used spring materials. The most popular alloys include high-carbon (such as the music wire used for guitar strings), oil-tempered low-carbon, chrome silicon, chrome vanadium, and stainless steel. Other metals that are sometimes used to make springs are beryllium copper alloy, phosphor bronze, and titanium. Rubber or urethane may be used for cylindrical, non-coil springs. Ceramic material has been developed for coiled springs in very high-temperature environments. One-directional glass fiber composite materials are being tested for possible use in springs.

Various mathematical equations have been developed to describe the properties of springs, based on such factors as wire composition and size, spring coil diameter, the number of coils, and the amount of expected external force. These equations have been incorporated into computer software to simplify the design process. Depending on the design and required operating environment, any material can be used to construct a spring, so long as the material has the required combination of rigidity and elasticity: technically, a wooden bow is a form of spring. But which material is best to use when designing a compression, extension or torsion spring is the primary challenges for the designer.

Selection of the most appropriate material for a spring device is one of the primary challenges often faced by the designers. As spring devices are able to store large amount of power, it should have sufficient strength so that they will not fail under static loading or dynamic loading during normal operating conditions. While selecting materials for spring device various material properties like tensile strength, modulus of elasticity, modulus in torsion, maximum operating temperature, hardness, density, cost etc. are to be taken into consideration. The present study involves PROMETHEE method as mathematical tool to select the most appropriate spring material from a given set of alternatives spring materials.

II. LITERATURE SURVEY

Thus to taken in well thought-out the provisions of the spring manufacturing industries, researcher have paid unrelenting attention for searching appropriate materials for spring. Kaiser et al [1] reports on procedure and preliminary research results of long-term fatigue tests up to a number of 109 cycles on shot peened helical compression springs with two basic dimensions, made of three different spring materials (oil hardened and tempered SiCr- and SiCrV-alloy steel). Their result shows that the various spring types in test exhibit different fatigue properties and also different failure mechanisms in the VHCF regime. Pöllänen et al. [2] proposed optimum design of the spring which minimize of wire volume, space restriction, desired spring rate, avoidance of surging frequency and achieving reliably long fatigue life. Their result was verified by using full 3D solid FEM analysis with MSC Nastran by which the stresses and also strains, deformations and natural frequencies and modes are obtained. Prawoto et al. [3] discusses about automotive suspension coil springs, their fundamental stress distribution, materials characteristic, manufacturing and common failures. An in depth discussion on the parameters influencing the quality of coil springs is also presented. Berger and Kaiser [4] reported that the results of very high cycle fatigue tests on helical compression springs which respond to external compressive forces with torsional stresses. The results of these investigations can add an important contribution to the experience of fatigue behavior in the very high cycle regime. Most investigations performed on that field deal with specimens under tensile or rotating bending load. These springs tested were manufactured of Si-Cr-alloyed valve spring wire with a wire diameter between 2 and 5 mm, shot-peened and preset. Compared to the fatigue limits evaluated in fatigue tests on these springs up to 107 cycles substantial decreases in fatigue strength are to be observed if the fatigue tests are continued up to 108 cycles or even more. It is obvious that nucleation's of fractures tending to occur below the surface, if fractures happen after more than 107 cycles. Investigations of broken springs by scanning electron microscope show a typical appearance of fracture initiation sites without non-metallic inclusions at the nucleation's of fracture.

III. PROMETHEE METHOD

The first paragraph under each heading or subheading should be flush left, and subsequent paragraphs should have a five-space indentation. A colon is inserted before an equation is presented, but there is no punctuation following the equation. All equations are numbered and referred to in the text solely by a number enclosed in a round bracket (i.e., (3) reads as "equation 3"). Ensure that any miscellaneous numbering system you use in your paper cannot be confused with a reference [4] or an equation (3) designation. (10)

The PROMETHEE I (partial ranking) and PROMETHEE II (complete ranking) were developed by J.P. Brans [5] and presented for the first time in 1982 at a conference. A few years later J.P. Brans and B. Mareschal developed PROMETHEE III (ranking based on intervals) and PROMETHEE IV (continuous case). In 1992 and 1994, J.P. Brans and B. Mareschal further suggested two nice extensions, PROMETHEE V (MCDA including segmentation constraints) and PROMETHEE VI (representation of the human brain). A considerable number of successful applications has been treated by the PROMETHEE methodology in various fields such as banking, industrial location, manpower planning, water resources, investments, medicine, chemistry, health care, tourism, ethics in OR, dynamic management etc. The success of the methodology is basically due to its mathematical properties and to its simplicity.

Many multicriteria decision aid methods have been proposed by researcher to deal the optimization problem. All the method start from the same evaluation table, but they vary according to the additional information they request. The PROMETHEE methods require very clear additional information that is easily obtained and understood by both decision makers and analysts.

The purpose of all multicriteria methods is to enrich the dominance graph, i.e. to reduce the number of incomparabilities(R). When a utility function is built, the multicriteria problem is reduced to a single criterion problem for which an optimal solution exists. This seems exaggerated because it relies on quite strong assumptions and it completely transforms the structure of the decision problem. For this reason B. Roy proposed to build outranking relations including only realistic enrichments of the dominance relation [6]. In that case, not all the incomparabilities are withdrawn but the information is reliable. The PROMETHEE methods belong to the class of outranking methods.

The PROMETHEE methods were designed to treat multicriteria problems, the additional information requested to run PROMETHEE is particularly clear and understandable by both the analysts and the decision-makers. It consists of information between the criteria; information within each criterion.

Table 1reveledthat the set {Wj= j, j=1,2,…,k} represents weights of relative importance of the different criteria. These weights are non-negative numbers, independent from the measurement units of the criteria.

Table 1 Weight of relative importance

$g_1(.)$	$g_2(.)$	….	$g_j(.)$	….	$g_k(.)$
W_1	W_2	….	W_j	….	W_k

The higher the weight, the more important the criterion. There is no objection to consider normed weights, so that:

$$\sum_{j=1}^{k} W_j = 1 \tag{1}$$

PROMETHEE is not allocating an intrinsic absolute utility to each alternative, neither globally, nor on each criterion. The preference structure of PROMETHEE is based on pair-wise comparisons. In this case the deviation between the evaluations of two alternatives on a particular criterion is considered. For small deviations, the decision-maker will allocate a small preference to the best alternative and even possibly no preference if decision maker considered that this deviation is negligible. The larger the deviation, the larger the preference. There is no objection to consider that these preferences are real numbers varying between 0 and 1. This means that for each criterion the decision-maker has in mind a function

$$P_j(a,b) = F_j\left[d_j(a,b)\right] \quad \forall a,b \in A, \tag{2}$$

Where:

$$d_j(a,b) = g_j(a) - g_j(b) \tag{3}$$

and for which:

$$0 \leq P_j(a,b) \geq 1 \tag{4}$$

In case of a criterion to be maximized, this function is giving the preference of ‘a’ over ‘b’ for observed deviations between their evaluations on criterion $g_j(a)$.The preferences equal 0 when the deviations are negative.

The following property holds:

$$P_j(a,b) > 0 \Rightarrow P_j(a,b) = 0. \tag{5}$$

For criteria to be minimized, the preference function should be reversed or alternatively given by:
$P_j(a,b) = F_j[-d_j(a,b)].$ (6)

Now called the pair $\{g_j(.), P_j(a,b)\}$, the generalized criterion associated to criterion $g_j(.)$. such a generalized criterion has to be defined for each criterion. In order to facilitate the identification six types of particular preference functions have been proposed.

Type 1: Usual criterion

$$P(d) = \begin{cases} 0 & d \le 1 \\ 1 & d > 1 \end{cases} \quad (7)$$

Type 2: U-shape criterion

$$P(d) = \begin{cases} 0 & d \le q \\ 1 & d > q \end{cases} \quad (8)$$

where 'q' is the fix parameter

Type 3: V-shape criterion

$$P(d) = \begin{cases} 0 & d \le 0 \\ \frac{d}{p} & 0 \le d \le p \\ 1 & d > p \end{cases} \quad (9)$$

where 'p' is the fix parameter

Type 4: Level criterion

$$P(d)= \begin{cases} 0 & d \le q \\ \frac{1}{2} & q < d \le p \\ 1 & d > p \end{cases} \quad (10)$$

where 'p,q' are the fix parameters

Type 5: V-shape with indifference

$$P(d) = \begin{cases} 0 & d \le q \\ \frac{d-p}{p-q} & q < d \le p \\ 1 & d > p \end{cases} \quad (11)$$

Where 'p,q' are the fix parameters

Type 6: Gaussian criterion

$$P(d)= \begin{cases} 0 & d \le 0 \\ 1 - e^{-\frac{d^2}{2s^2}} & < 0 \end{cases} \quad (12)$$

where's' is the fix parameter

In each case 0, 1 or 2 parameters have to be defined, their significance is clear, 'q' is a threshold or indifference; 'p' is a threshold of strict preference; 's' is an intermediate value between and 'p' and 'q'.

The indifference threshold is the largest deviation which is considered as negligible by the decision maker, while the preference threshold is the smallest deviation which is considered as sufficient to generate a full preference. The identification of a generalized criterion is then limited to the selection of the appropriate parameters. It is an easy task.

In case of type 5 (V-shape with indifference) a threshold of indifference 'q' and a threshold of strict preference 'p' have to be selected. Gaussian criterion (type 6) the preference function remains increasing for all deviations and has no discontinuities, neither in its shape, nor in its derivatives. A parameter has to be selected; it defines the inflection point of the preference function. It is then recommend to determine first a 'q' and a 'p' and to fix in between 's'. If's' is close to the 'q' preferences will be reinforced for small deviation, while close to 'p' they will be softened.

As soon as the evaluation table $\{g_j(.)\}$ is given, and the weights wj and the generalized criteria $\{g_j(.), P_j(a,b)$ } are defined for i=1,2,…,n; j=1,2,….,k, the PROMETHEE procedure can be applied.

The PROMETHEE I procedure is based on pair-wise comparisons [7]. Let us first define aggregated preference indices and outranking flows.

Let, a, b Є A, and let:

$$\begin{cases} \pi(a,b) = \sum_{j=1}^{k} P_j\,(a,b) w_j \\ \pi(b,a) = \sum_{j=1}^{k} P_j\,(b,a) w_j \end{cases} \tag{13}$$

$\pi(a,b)$is expressing with which degree 'a' is preferred to 'b' over all the criteria and $\pi(b,a)$ how 'b' is preferred 'a'. In most of the cases there are criteria for which 'a' is better than 'b', and criteria for which 'b' is better than 'a', consequently $\pi(a,b)$ and $\pi(b,a)$ are usually positive.

The following properties holds for all (a, b) Є A.

$$\begin{cases} \pi(a,a) = 0, \\ 0 \le \pi(a,b) \le 1, \\ 0 \le \pi(b,a) \le 1, \\ 0 \le \pi(a,b) + \pi(b,a) \le 1 \end{cases} \tag{14}$$

It is clear that:

$$\begin{cases} \pi(a,b) \sim impliesaweakglobalpreferenceofaoverb, \\ \pi(b,a) \sim impliesastrongglobalpreferenceofaoverb. \end{cases} \tag{15}$$

Each alternative 'a' is facing (n-1) other alternatives in *A*. Let us define the two following outranking flows:

The positive out ranking flow:

$$\emptyset^{+}(a) = \frac{1}{n-1} \sum_{x \in A} \pi(a,x), \tag{16}$$

The negative out ranking flow:

$$\emptyset^{-}(a) = \frac{1}{n-1} \sum_{x \in A} \pi(x,a). \tag{17}$$

The positive outranking flow expresses how an alternative 'a' is outranking all the others. It is its power, its outranking character. The higher $\emptyset^{+}(a)$, the better the alternative. The negative outranking flow expresses how an alternative 'a' is outranked by all the others. It is its weakness, its outranked character. The lower $\emptyset^{-}(a)$, the better the alternative.

The PROMETHEE I partial ranking (P^I, I^I, R^I) is obtained from the positive and the negative outranking flows. Both flows do not usually induce the same rankings. PROMETHEE I is their intersection.

$$\begin{cases} aP^I biff \begin{cases} \emptyset^{+}(a) > \emptyset^{+}(b) and \emptyset^{-}(a) < \emptyset^{-}(b), or \\ \emptyset^{+}(a) = \emptyset^{+}(b) and \emptyset^{-}(a) < \emptyset^{-}(b), or \\ \emptyset^{+}(a) > \emptyset^{+}(b) and \emptyset^{-}(a) = \emptyset^{-}(b); \end{cases} \\ aI^I biff \emptyset^{+}(a) = \emptyset^{+}(b) and \emptyset^{-}(a) = \emptyset^{-}(b); \\ aR^I biff \begin{cases} \emptyset^{+}(a) > \emptyset^{+}(b) and \emptyset^{-}(a) > \emptyset^{-}(b), or \\ \emptyset^{+}(a) < \emptyset^{+}(b) and \emptyset^{-}(a) < \emptyset^{-}(b); \end{cases} \end{cases} \tag{18}$$

Where P^I, I^I, R^I respectively stand for preference, indifference and incomparability.

WhenaP^Ib a higher power of 'a' is associated to a lower weakness of 'a' with regard to 'b'. The information of both outranking flows is consistent and may therefore be considered as sure. When aI^Ib, both positive and negative flows are equal. When aR^Ib, a higher power of one alternative is associated to a lower weakness of the other. This often happens when 'a' is good on a set of criteria on which 'b' is weak and reversely 'b' is good on some other criteria on which 'a' is weak. In such a case the information provided by both flows is not consistent. It seems then reasonable to be careful and to consider both alternatives as incomparable. The PROMETHEE I ranking is prudent: it will not decide which action is best in such cases. It is up to the decision-maker to take his responsibility.

Promethee II is a well-established decision support system [8, 9] is used to rank the different options based on selected criteria. In this paper, the PROMETHEE II method is employed to obtain the full ranking of the alternative locations for a given industrial application.

The procedural steps as involved in PROMETHEE II method are enlisted as below [5, 10]

Step 1: Normalize the decision matrix using the following equation:

$$R_{ij} = \frac{[X_{ij} - min(X_{ij})]}{[max(X_{ij}) - min(X_{ij})]} \quad (i = 1,2,\ldots,n : j = 1,2,..,m) \tag{19}$$

Where X_{ij} is the performance measure of ith alternative with respect to jth criterion.

For non-beneficial criteria, Eqn. (12) can be rewritten as follows:

$$R_{ij} = \frac{[max(X_{ij}) - X_{ij}]}{[max(X_{ij}) - min(X_{ij})]} \tag{20}$$

Step 2: Calculate the evaluative differences of ith alternative with respect to other alternatives. This step involves the calculation of differences in criteria values between different alternatives pair-wise.

Step 3: Calculate the preference function $P_j(i, i')$.

There are mainly six types of generalized preference functions as proposed by Brans and Mareschal [10]. But these preference functions require the definition of some preferential parameters, such as the preference and indifference thresholds. However, in real time applications, it may be difficult for the decision maker to specify which specific form of preference function is suitable for each criterion and also to determine the parameters involved. To avoid this problem, the following simplified preference function is adopted here:

$$P_j(i, i') = 0 \; if R_{ij} \leq R_{ji'} \tag{21}$$

$$P_j(i, i') = (R_{ij} - R_{ji'}) if R_{ij} > R_{ji'} \tag{22}$$

Step 4: Calculate the aggregated preference function taking into account the criteria weights.

Aggregated preference function, $\pi(i, i') = \frac{[\sum_{j=1}^{m} W_j \times P_j(i,i')]}{\sum_{j=1}^{m} W_j}$ (23)

Where W_j is the relative importance (weight) of jth criterion.

Step 5: Determine the leaving and entering outranking flows as follows:

Leaving (or positive) flow for ith alternative, $\emptyset^+(i) = \frac{1}{n-1} \sum_{i'=1}^{n} \pi(i, i') i \neq i'$ (24)

Entering (or negative) flow for ith alternative, $\emptyset^-(i) = \frac{1}{n-1} \sum_{i'=1}^{n} \pi(i', i) i \neq i'$ (25)

Where n is the number of alternatives.

Here, each alternative faces (n – 1) number of other alternatives. The leaving flow expresses how much an alternative dominates the other alternatives, while the entering flow denotes how much an alternative is dominated by the other alternatives. Based on these outranking flows, the PROMETHEE I method can provide a partial preorder of the alternatives, whereas, the PROMETHEE II method can give the complete preorder by using a net flow, though it loses much information of preference relations.

Step 6: Calculate the net outranking flow for each alternative.

$$\emptyset(i) = \emptyset^+(i) - \emptyset^-(i) \tag{26}$$

Step 7: Determine the ranking of all the considered alternatives depending on the values of $\emptyset(i)$. The higher value of $\emptyset(i)$, the better is the alternative. Thus, the best alternative is the one having the highest $\emptyset(i)$ value.

The PROMETHEE method is an interactive multi-criteria decision-making approach designed to handle quantitative as well as qualitative criteria with discrete alternatives. In this method, pair-wise comparison of the alternatives is performed to compute a preference function for each criterion. Based on this preference function, a preference index for alternative i over i′ is determined. This preference index is the measure to support the hypothesis that alternative i is preferred to i′. The PROMETHEE method has significant advantages over the other MCDM approaches, e.g. multi-attribute utility theory (MAUT) and AHP. The PROMETHEE method can classify the alternatives which are difficult to be compared because of a trade-off relation of evaluation standards as non-comparable alternatives. It is quite different from AHP in that there is no need to perform a pair-wise comparison again when comparative alternatives are added or deleted.

IV. SPRING MATERIAL SELECTION

Frequently, the operating environment is the single most important consideration for proper spring material selection. For successful application, material must be compatible with the environment and withstand effects of temperature and corrosion without an excessive loss in spring performance. Corrosion and elevated temperatures decrease spring reliability. The effect of temperature on spring materials is predictable.

When specifying a compression or a tension spring, designers will be aware of the forces and degree of accuracy required, together with the operational conditions. From this information, designers must select a material from which a spring can be made. A maximum permissible stress can then be determined, which, together with the load requirements, will enable suitable dimensions to be selected.

Hence, in order to apply PROMETHEE II method to solve the spring material selection problem and prove its potentiality and universal applicability for dealing with this type of complex decision-making problem, the corresponding decision matrix of Table 1 is developed. This decision-matrix comprising of seven spring material alternative and eight important selection criteria. Most of the criteria values of Table 1 are taken from handbook/ website [11,12]. The details of these eight selection criteria are given in Table 2.

This decision matrix consists of seven spring materials and eight pivotal selection criteria. All the criteria values of Table 1 are accumulated from different handbooks. The details of these eight selection criteria are given in Table 2.

Tensile strength measures the force required to pull something such as rope, wire, or a structural beam to the point where it breaks. The tensile strength of a material is the maximum amount of tensile stress that it can take before failure. An elastic modulus, or modulus of elasticity, is the mathematical description of an object or substance's tendency to be deformed elastically (i.e., non-permanently) when a force is applied to it. The elastic modulus of an object is defined as the slope of its stress–strain curve in the elastic deformation region. As such, a stiffer material will have a higher elastic modulus. It defines the ratio of stress and strain. It is a measure of an object's ability to resist torsion. It is required to calculate the twist of an object subjected to a torque. It is analogous to the area moment of inertia, which characterizes an object's ability to resist bending and is required to calculate displacement. The larger the modulus in torsion, the less the beam will twist, when subjected to a given torque. In between which temperature the materials can work without any kind of change of stage and can give the maximum efficiency. Larger the value of Maximum operating temperature the material can withstand that much temperature. Hardness is the measure of how resistant solid matter is to various kinds of permanent shape change when a force is applied. The Rockwell scale is a hardness scale based on the indentation hardness of a material. The Rockwell test determines the hardness by measuring the depth of penetration of an indenter under a large load compared to the penetration made by a preload. The mass density or density of a material is defined as its mass per unit volume. Density is a physical property of matter, as each element and compound has a unique density associated with it. Density defined in a qualitative manner as the measure of the relative "heaviness" of objects with a constant volume. The cost of a spring material indicates its current market price which greatly influences the final spring cost. It is expressed in terms of the price value per unit weight of the spring material. So, its cost should be as low as possible and is taken as a non-beneficial criterion.

Table 3 shows an exhaustive list of the seven alternative supercritical boiler materials. The composition of high carbon steel ASTMA 228 is C 0.70 - 1.00% and Mn 0.20 – 0.60%. Music Wire ASTMA 228 are the most commonly used of all springs materials. These materials in preference to others because that are least expensive, readily available, easily worked, and most popular. These materials are not satisfactory for high or low temperatures or for shock or impact loading. This high quality high-carbon spring wire is the most common and readily available today. You might say that music wire will give you the biggest bang for your buck. This material is widely used for helical compression, extension and torsion springs in a wide range of applications, especially in the finer wire diameters. Known for its high tensile strength, high elastic limit, and music wire can withstand high stresses under repeated loadings, and will continue to perform well under many normal cyclic applications. The composition of Beryllium Copper ASTM B 197 is Cu 98.0% and Be 2.0%.Copper-base alloys are important spring materials because of their good electrical properties combined with their excellent resistance to corrosion. Although these materials are more expensive than the high-carbon and the alloy steels, they nevertheless are frequently used in electrical components and in subzero temperatures. All copper-base alloys are drawn to the American wire gage (same as Brown & Sharpe gage) and are nonmagnetic. The composition of Monel K 500 - QQ-N-286 is Ni 63.0%, Cu 29.5%, Al 2.7%, Ti 0.6%, C 0.18%, Fe 2.0%, Mn 1.5%, Si 0.50%, S 0.010%. Alloy K-500 is a nickel-copper alloy, precipitation hardenable through additions of aluminum and titanium. This alloy retains the excellent corrosion resistant characteristics of 400 and has enhanced strength and hardness after precipitation hardening when compared with 400. Alloy K-500 has approximately three (3) times the yield strength and double the tensile strength when compared with 400. K-500 can be further strengthened by cold working before the precipitation hardening. Excellent mechanical properties from sub-zero temperatures up to about 480C. Corrosion resistance in an extensive range of marine and chemical environments. The composition of Chrome Silicon ASTM A 401 is C 0.51 - 0.59%, Cr 0.60 - 0.80%, Si 1.20 - 1.60%.The alloy spring steels have a definite place in the field of spring materials, particularly for conditions involving high stress and for applications where shock or impact loading occurs. Alloy spring steels also can withstand higher and lower temperatures than the high-carbon steels and are obtainable in either the annealed or pre tempered conditions. These materials are not regularly stocked in a wide variety of sizes. The composition of AISI 302/304 Stainless Steel is Cr 17.0 - 19.0% and Ni 8.0 - 10.0%. The use of stainless spring steels has increased considerably in recent years. Several new compositions are now available to withstand corrosion. All of these materials can be used for high temperatures up to 650°F.The composition of Inconel 600 - QQ-W-390 is Ni 76.0%, Cr 15.8% and Fe 7.2%. Nickel-based alloys are especially useful spring materials to combat corrosion and to withstand both elevated and below-zero temperature application. Their nonmagnetic characteristic is important for such devices as gyroscopes, chronoscopes, and indicating instruments. These materials have high electrical resistance and should not be used for conductors of electrical current. The composition of Nickel Alloy is C 0.08,Mn 2,Al 0.35,Ni 24-27,P 0.025, S 0.025, Cr 13.5-16, Si 1,Mo 1-1.5, Ti 1.9-2.35,Vd 0.1-0.5,B 0.003-0.01,Fe balance. Type A286 alloy content is similar in chromium, nickel, and molybdenum to some of the austenitic stainless steels. Consequently, A286 alloy possesses a level of aqueous corrosion resistance comparable to that of the austenitic stainless steels. In elevated temperature service, the level of corrosion resistance to atmospheres such as those encountered in jet engine applications is excellent to at least 1300°F (704°C). Oxidation resistance is high for continuous service up to 1500°F (816°C) and intermittent service up to 1800°F (982°C).

V. CALCULATION

For solving this spring material selection problem using PROMETHEE II method, the decision matrix of Table1 is taken. Considering both beneficial and non-beneficial criteria, the decision matrix, as shown in Table 1, is normalized using Equation (19) and (20) is given in Table 5. The leaving (positive) and the entering (negative) flows for different spring material alternatives are now computed using Equations (24) and (25), respectively, and are shown in Table 6. The net outranking flow values for the spring material alternatives are calculated using Equation (26) and is given in Table 7 Now, after arranging the spring material alternative in descending order of their net outranking flow values, ranking of different spring material alternatives are also given in Table 7. It is observed that Chrome Silicon Alloy Steel (ASTM A 401) is the most appropriate choice as a spring material. High Carbon Steel (ASTM A 228) and Inconel 600 may also be used as a spring materials because of these materials obtain second and third ranks. Monel K500 is a worst material for spring.

VI. LIST OF TABLES

Table 1 Decision matrix for spring material selection problem

Alternatives	B1	B2	B3	B4	B5	B6	B7	B8
A1	2168.5	207	45	79.3	121	50.5	7.85	35
A2	1310	128	45	48.3	204	38.5	8.26	33
A3	1241	179	40	65.5	288	29	8.44	55
A4	1844.5	207	45	79.3	245	51.5	7.85	30
A5	1551.5	193	35	69	288	40	7.92	15
A6	1379	214	40	75.8	371	40	8.47	45
A7	1241	200	35	71.7	510	38.5	7.92	32

Table 2 Criteria for spring material selection

Properties of Spring Material	Symbols
Tensile Strength (MPa)	B1
Modulus of Elasticity (GPa)	B2
Design Stress percentage Min. Tensile (%)	B3
Modulus in Torsion (GPa)	B4
Max. Operating Temp (˚C)	B5
Rockwell Hardness (HRC)	B6
Density (gm/cc)	B7
Material Cost ($/Kg.)	B8

Table 3 Spring materials

Materials	Symbols
High Carbon Steel (ASTM A 228)	A1
Beryllium Copper Alloy (ASTM B 197)	A2
Monel K500	A3
Chrome Silicon Alloy Steel (ASTM A 401)	A4
Stainless Steel (AISI 304)	A5
Inconel 600	A6
Nickel Alloy(ASTM A 286)	A7

Table 4 Weights for different criteria.

Criteria	B1	B2	B3	B4	B5	B6	B7	B8
Weight	0.7680	0.0679	0.0103	0.0203	0.1133	0.0105	0.0012	0.0086

Table 5 Normalized decision matrix for spring material selection problem

Alternatives Materials	B1	B2	B3	B4	B5	B6	B7	B8
A1	1.0000	0.9186	1.0000	1.0000	0.0000	0.9556	1.0000	0.5000
A2	0.0744	0.0000	1.0000	0.0000	0.2134	0.4222	0.3387	0.5500
A3	0.0000	0.5930	0.5000	0.5548	0.4293	0.0000	0.0484	0.0000
A4	0.6507	0.9186	1.0000	1.0000	0.3188	1.0000	1.0000	0.6250
A5	0.3348	0.7558	0.0000	0.6677	0.4293	0.4889	0.8871	1.0000
A6	0.1488	1.0000	0.5000	0.8871	0.6427	0.4889	0.0000	0.2500
A7	0.0000	0.8372	0.0000	0.7548	1.0000	0.4222	0.8871	0.5750

Table 6 Leaving and entering flows for different spring materials

Alternatives	Leaving (Positive) flow	Entering (Negative) flow
A1	0.4119	0.0128
A2	0.0683	0.4186
A3	0.0442	0.4622
A4	0.4385	0.0050
A5	0.1264	0.1754
A6	0.1146	0.1211
A7	0.1139	0.1800

Table 7 Net outranking flow values & corresponding ranking for different spring material

Alternatives	Net outranking flow	Ranking
A1	2.3992	2
A2	1.6497	6
A3	1.5821	7
A4	2.4335	1
A5	1.9510	4
A6	1.9934	3
A7	1.9339	5

VII. CONCLUSION

As of the literature survey, it is observed that the past researches have took the help of different experimental techniques for mechanical properties characterization to aid the spring designer select the best spring material for particular type of spring, there is a fervent requirement for an efficient mathematical approach to solve the spring material selection problem. In this paper, PROMETHEE II method is applied to select the best material for a given spring. The observed results are accurately in accordance with the expected choices. Hence, in many real times decision-making situations, where the evaluation is done using quantitative and qualitative data, this method can be efficiently used to obtain more precise results. This method can be extended to support and increase the efficiency of the decision-making process related to selection of materials for other engineering applications.

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