Integrated Topsis-Entropy Method for Electromagnet Material Selection

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Abstract - An electromagnet is a device that generates a magnetic field through an electric current flowing via a coil wound around a magnetic core. While various materials can be used for electromagnet fabrication, selecting the optimal material remains a complex task due to the simultaneous consideration of multiple, often conflicting, parameters. This study integrates the TOPSIS and Entropy methods to select the best material among ten available alternatives. The ten materials considered include Pure Iron, Low Carbon Steel, Silicon Steel, Permalloy, Mumetal, Soft Ferrite, Sendust, Metglas, Permendur, and Nanocrystalline. To evaluate these materials, the Entropy method was employed to calculate the weights of criteria, including relative permeability, saturation induction, electrical resistivity, coercive force, Curie temperature, and stacking factor. Subsequently, the TOPSIS method was used to rank the materials and determine the optimal solution. The findings indicate that Metglas is the most suitable material for electromagnet fabrication.

Keywords: Electromagnet material selection, MCDM, TOPSIS, Entropy.

1. INTRODUCTION

An electromagnet is a device that generates a magnetic field when an electric current passes through a coil wound around a ferromagnetic core. Due to their ability to flexibly control magnetic force (on/off), electromagnets are widely applied in domestic and industrial sectors, ranging from household devices like electric bells and speakers to complex systems such as scrap cranes, Magnetic Resonance Imaging (MRI) machines, and high-speed maglev trains. Currently, there is a vast diversity of materials available for electromagnets, spanning traditional electrical steels and Permalloy alloys to modern Soft Ferrites. However, selecting the optimal material is a complex engineering problem requiring designers to carefully balance conflicting parameters. For instance, an ideal material should possess high relative permeability and saturation induction to generate strong attraction, but simultaneously require a minimal coercive force to release the object immediately when the power is cut. Furthermore, factors such as high electrical resistivity (to reduce heat dissipation), a sufficiently high Curie temperature (for harsh environments), and an optimal stacking factor (to minimize device size) present significant hurdles for achieving peak efficiency. To address this complexity, Multi-Criteria Decision-Making (MCDM) methods are considered highly suitable [1-3]. Among the hundreds of MCDM methods proposed, this study utilizes TOPSIS, which is recognized as one of the most widely used approaches [4, 5]. Since most MCDM methods, including TOPSIS, require the determination of criteria weights, this study employs the Entropy method—a highly accurate and popular technique for weight calculation [6, 7]. Section 2 of this paper summarizes the steps of the Entropy and TOPSIS methods. Section 3 presents the ranking of ten electromagnet materials to select the best option, followed by the conclusion.

2. METHODOLOGY

2.1. Entropy Method

The determination of criteria weights using the Entropy method is conducted through the following steps [8]:

Step 1: Construct a decision matrix consisting of m rows and n columns as shown in formula (1), where m and n represent the number of alternatives and criteria, respectively. Let y_{ij} be the value of criterion j for alternative i. The letters B and C denote "Benefit" (the larger the better) and "Cost" (the smaller the better) criteria, respectively.

$$Y = \begin{bmatrix} y_{11} & y_{12} & \cdots & y_{1n} \\ y_{21} & xy_{22} & \cdots & y_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ y_{m1} & y_{m2} & \cdots & y_{mn} \end{bmatrix} \tag{1}$$

Step 2: Determine the normalized values for the criteria using formula (2).

$$p_{\mathrm{ij}} = \frac{y_{\mathrm{ij}}}{m + \sum_{i=1}^{m} y_{\mathrm{ij}}^2} \tag{2}$$

Step 3: Calculate the Entropy measure for each criterion using formula (3).

$$e_j = -\sum_{i=1}^{m}\left[p_{ij} \times \ln(p_{ij})\right] - \left(1 - \sum_{i=1}^{m} p_{ij}\right) \times \ln\left(1 - \sum_{i=1}^{m} p_{ij}\right) \quad (3)$$

Step 4: Calculate the weight for each criterion using formula (4).

$$w_j = \frac{1 - e_j}{\sum_{j=1}^{m}(1 - e_j)} \quad (4)$$

2.2. TOPSIS Method

The steps for the TOPSIS method are described as follows [9]:

Step 1: Same as Step 1 of the Entropy method.

Step 2: Determine the conversion values using formula (5).

$$y'_{ij} = \frac{y_{ij}}{\sqrt{\sum_{i=1}^{n} y_{ij}^2}} \quad (5)$$

Step 3: Calculate the weighted normalized matrix using formula (6), where wj is the weight of criterion j.

$$Y = w_j . y'_{ij} \quad (6)$$

Step 4: Determine the Positive Ideal Solution (A^+) and the Negative Ideal Solution (A^-) using formulas (7) and (8).

$$A^+ = \{y_1^+, y_2^+, \dots, y_j^+, \dots, y_n^+\} \quad (7)$$

$$A^- = \{y_1^-, y_2^-, \dots, y_j^-, \dots, y_n^-\} \quad (8)$$

Step 5: Determine the separation measures (Si^+ and Si^-) using formulas (9) and (10).

$$S_i^+ = \sqrt{\sum_{j=1}^{n}(y_{ij} - y_j^+)^2} \qquad i = 1, 2, \dots, m \quad (9)$$

$$S_i^- = \sqrt{\sum_{j=1}^{n}(y_{ij} - y_j^-)^2} \qquad i = 1, 2, \dots, m \quad (10)$$

Step 6: Determine the relative closeness (Ci) using formula (11).

$$C_i = \frac{S_i^-}{S_i^+ + S_i^-} \qquad i = 1, 2, \dots, m;\ 0 \le C_i^* \le 1$$

Step 7: Rank the alternatives; the alternative with the highest Ci is considered the best solution.

3. ELECTROMAGNET MATERIAL SELECTION

Ten materials commonly used for electromagnets are summarized in Table 1, labeled as alternatives A1 through A10 [10]. Six criteria (C1 to C6) were used to characterize each material:

Relative Permeability (C1): Indicates the material's ability to conduct magnetic flux compared to a vacuum. Higher values allow for easier magnetization and stronger force with lower current.

Saturation Induction (C2): The maximum limit of magnetic flux density the material can hold.

Electrical Resistivity (C3): Vital for reducing eddy currents that cause core heating.

Coercive Force (C4): Measures the material's ability to withstand an external magnetic field without becoming demagnetized (lower is generally better for electromagnets).

Curie Temperature (C5): The temperature at which the material loses its permanent magnetic properties.

Stacking Factor (C6): Reflects the optimization of space between the core and the windings.

Among these, C4 is a "Cost" criterion (C), while the others are "Benefit" criteria (B).

Table 1. Electromagnet materials [10]

Alt.	Material	C1	C2	C3	C4	C5	C6
		B	B	B	C	B	C
		μr	Bs	μΩ·m	A/m	^{0}C	-
A1	Pure Iron	5	2.15	0.10	40	770	1.0
A2	Low Carbon Steel	2	2.10	0.15	100	770	1.0
A3	Silicon Steel	10	02.01	0.48	30	740	0.95
A4	Permalloy	100	0.75	0.55	1.5	400	0.90
A5	Mumetal	250	0.80	0.60	0.8	400	0.90
A6	Ferrite Soft	2	0.40	106	15	200	1.0
A7	Sendust	120	01.05	0.80	2.0	500	0.85
A8	Metglas	600	1.56	1.30	0.5	395	0.80
A9	Permendur	5	2.43	0.07	160	980	1.0
A10	Nanocrystalline	150	1.25	1.15	1.0	570	0.80

Data from Table 1 shows that no single material excels across all six criteria. For instance, C1 is highest at A8, C2 is highest at A9, and C3 peaks at A6. Therefore, an MCDM approach is necessary to identify the "best" overall option. By applying formulas (1) through (4), the criteria weights were calculated and summarized in Table 2.

Table 2. Weights of the criteria

C1	C2	C3	C4	C5	C6
0.1239	0.2376	0.1265	0.1275	0.1233	0.2612

Table 2 reveals that C6 (Stacking Factor) is the most significant parameter, indicating that a compact design with minimal air gaps is crucial for reducing magnetic loss and increasing efficiency. After determining the weights, formulas (5) through (11) were used to calculate the Ci scores for the ten materials, resulting in the ranking shown in Figure 1.

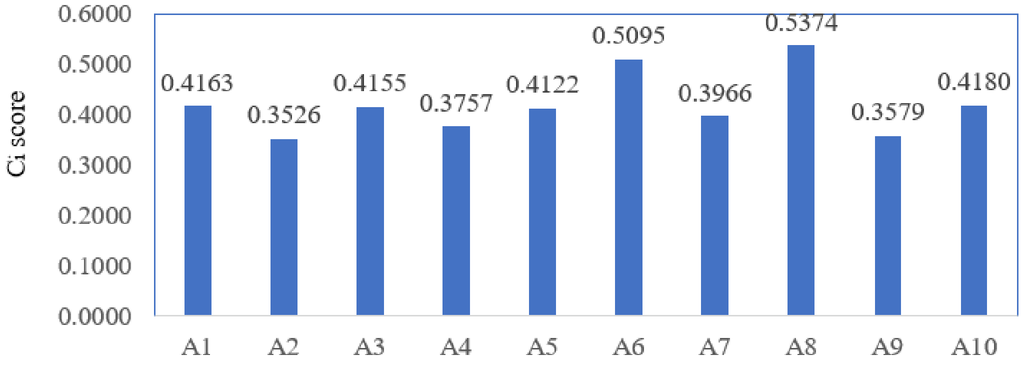

Figure 1. C_i scores of the materials

As observed in Figure 1, Metglas (A8) achieved the highest score of 0.5374, making it the optimal choice. This material features a Relative Permeability of 600 (μr), Saturation Induction of 1.56 (Bs), Electrical Resistivity of 1.30 (μΩ·m), Coercive Force of 0.5 (A/m), Curie Temperature of 395 (^{0}C), and a Stacking Factor of 0.8.

CONCLUSION

This study integrated the TOPSIS and Entropy methods to rank ten electromagnet materials based on six technical criteria. The results highlight that the stacking factor is the most critical parameter in material selection for this application, and Metglas was identified as the most suitable material for electromagnet fabrication.

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