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Attribute based Specification, Comparison and Selection of Nanoactuator Elements

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Abstract*—*Organizations are deploying well designed nanoactuators supporting converged applications of defence, mechanical industry, and biological applications, etc. Optimum selection of nanoactuator elements for R & D of nanodevices for given application satisfying desired aims and objectives is a multiple attribute/criteria/objective decision making problem. The paper proposes technique for order preference by similarity to ideal solution (TOPSIS) to evaluate and rank nanoactuator elements in the presence of multiple attributes for solving the nanoactuator elements selection problem. The method normalizes attributes of nanoactuator elements to nullify the effect of different units and their values in the range of 0 to 1. The relative importance of different attributes of nanoactuator elements for different applications is considered. Euclidean distance of alternatives from these best and worst solutions of nanoactuator elements leads to the development of proximity /goodness/suitability index for ranking of nanoactuator elements. The method ensures that optimally selected nanoactuator elements are closest to the hypothetical best and farthest from the hypothetical worst solution. Research methodology in the form of step-by-step procedure is implemented with the help of an illustrative example.

Index Terms*—*Nanoactuator elements selection; MADM; TOPSIS; Pertinent attributes; Weighted normalization; Ranking;

I. INTRODUCTION

Recent advances in precision engineering and the concurrent development of advanced manufacturing techniques have the result that the machined and manufactured components are no longer restricted to micrometer scale but now fabricated at nanometre scale also. For the past few decades, nanotechnology has greatly influenced all science and engineering branches including physics electronics [1], civil engineering [2], material engineering [3], etc. In the electronic world, nanoelectromechanical systems (NEMS) have become the center of interest for developing ultra-small devices. Nanotechnology distinct from devices, which are merely, miniaturized versions of an equivalent macroscopic device; such devices are on a larger scale and come under the description of micro technology. It is hoped that developments in nanotechnology make possible their construction by some other means, perhaps usingbio-mimetic principles. Nanotechnology is able to create many new nanoactuator elements and nanodevices with a vast range of applications, such as in medicine, electronics, biomaterials, and energy production.

An ever increasing variety of nanoactautor elements is available today, with each having its own characteristics, applications, advantages, and limitations. When selecting nanoactuator elements for engineering designs, a clear understanding of the functional requirements for each individual component is required and various important criteria or attributes need to be considered. The selection of attributes for nanoactuator elements is defined as attribute that influences the selection of nanoactautor elements for a given application. These attributes include: physical properties, electrical properties, magnetic properties, mechanical properties, chemical properties, manufacturing properties, nanoactuator elements cost, product shape, nanoactuator elements impact on environment, availability, fashion, market trends, cultural aspects, aesthetics, recycling, target group, etc. So, selection of nanoactuator elements is one of the most challenging issues in the design and developmentof structural elements and it is also critical for the success and competitiveness of the manufacturingorganisation. Selection of the appropriate nanoactuator elements is an integral part of successfully implementation of an engineer's design. Proper selection of nanoactuator elements for designing nanoactuators that support converged applications, require careful considerations of type of applications that the nanoactuators design need to support and the type of nanoactuators design resources these applications require. The importance of materials selection in engineering design has been well recognized. The design decision-making regarding selecting appropriate materials is dictated by the specific requirements of an application, often the requirements on materials properties [4]. Recent developments in design, selection of nanoactuator elements play an important role for engineers. The core objective of nanoactuator elements selection procedure is to identify the attributes for selection of nanoactuator elements and to obtain the most appropriate combination of attributes in conjunction with the feasible requirements [5]. A systematic and efficient approach for selection of nanoactuator elements is necessary in order to select the best alternatives for a given application [6-10]. The selection decisions are complex, as nanoactuator elements selection is more challenging today. Thus, efforts need to be extended to identify those attributes that influence nanoactuator elements selection for a given engineering design to eliminate unsuitable alternatives, and to select the most appropriate alternatives using simple and logical methods. There are large number of issues that must be considered related to manufacturing, production processes, planning and control, conceptual design, detail design, nanoactuator elements properties selection, assembly, installation, maintenance, and disposal during R

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& D of any nanoproducts.

Some are common to all the applications while other pertain to a subset of applications. For example, the physical behavior of the actuators has been extensively studied in micro scales not at nanoscales. One of the most important effects that appear at nanoscale dimensions is the size dependency of material characteristics. The mechanism of thermal actuation has been widely investigated and it is under progress which needs more time to grow. For designing nanoactuators rack system needs a lot of components that must be machined and assembled. Moreover, positioning system for this does not allow backwards motion due to the asymmetry of the rack teeth. It is still to be chosen between the inertial drive principle and the crawling principle. But when the size of a positioning system is doubled, factors of 16 more acoustic noises are coupled into it. Despite all of the useful properties of nanoactuator elements (carbon nanotubes, piezoelectric material, etc.) for NEMS technology, it faces several hindrances in their implementation. One of the main problems is carbon's response to real life environments. The next challenge to overcome involves understanding all of the properties of these carbon based tools and using the properties to make efficient and durable NEMS with low failure rate NEMS devices. So, selection of nanoactuator elements for designing nanoactuators in a minimum possible time without considering all the issues is critical one. It requires nanoactuator elements having various attributes under broad categories (Like, actuation, modelisation, realization, and performance) with more or less equal importance. Most of the research contributions have been published in the field of actuation, optimization, performance and modelisation of nanoactuators. Most of these studies focus on individual ability at one time. Relatively not even a single literature is available for selection of nanoactuator elements using multiple attribute decision making (MADM) approach. Many researchers contributed in the field of manufacturing and construction sector of nanodevices including nanoactuators by considering various models and physical characteristics/attributes/properties depending on various applications. Like, the physical behavior of the torsional actuators has been extensively studied in micro scales [9-14]. Nevertheless, progress on innovative nanomaterials and methodologies has been demonstrated with some patents granted about new nanomanufacturing devices for future commercial applications, which progressively helps in the development towards nanorobots with the use of embedded nanobioelectronics concepts (Cavalcanti et al. [15], Boukallel et al. [16]). Drexler et al. [17] and other researchers have proposed that advanced nanotechnology although perhaps initially implemented by bio mimetic means, ultimately could be based on mechanical engineering principles, namely manufacturing technology based on the mechanical functionality of these components (such as gears, bearings, motors, and structural members) that would enable programmable, positional assembly to atomic specification.Nanorobotics centres on self-sufficient machines of some functionality operating at the nanoscale. There are hopes for applying nanorobots in medicine (Ghalanbor et al. [18], Kubik et al. [19] Leary et al. [20]) but it is not so easy to do such a thing, because of several drawbacks of such devices (Shetty et al. [21]). Nemirovsky et al. [22] were the first who introduced a lumped-mass model to capture the torsion/bending coupled behaviour of torsional micro-actuators. Recently researchers have investigated and implemented the mechanism of thermal actuation to build MEMS actuators. Drexler et al. have devised and studied different nano and micro scale machines, devices and actuators [23-25]. Lyshevski et al. have reported and demonstrated synthesis and classification solver for nanomachines and nanoactuators [25]. Darby et al. [26] have realized both linear and piezoelectric stick-slip actuators. Hu et al. have realized that with nanotechnology development, mechanical actuators capable of working with nanoscale precision positioning are essential for active devices which are compatible for high density on-chip integration [27]. Li et al. have observed and experimentally demonstrated that with the development of nanofabrication technology, optical force in nanomechanical structures [28]. Many researchers use various methods for selection of materials according to different application. Shanian and Savadogo [28] presented material selection models using a multiple attribute decision making (MADM) method known as ELECTRE. However, ELECTRE method uses the concept of outranking relationship and the procedure is rather lengthy. Shanian and Savadogo [29] applied TOPSIS method as multiple-criteria decision support analysis for material selection of metallic bipolar plates for polymer electrolyte fuel cell. However, the TOPSIS method proposed by them does not take into account the qualitative nature of the material selection attributes. Rao et al. [30, 31] presented a material selection model using graph theory and matrix approach. However, the method does not have a provision for checking the consistency in the judgments of relative importance of the attributes. Rao and Davim [32] proposed TOPSIS method combined with AHP for material selection. Manshadi et al. [33] proposed numerical method for the material selection combining non-linear normalization with modified digital logic method. However, the method does not make a provision for considering the qualitative material selection attributes. From the above literature it reveals that various methodologies have already been used by the past researchers for proper material selection. Like a compromise ranking and outranking methods were applied for the selection of material for design of a flywheel etc. During the past few years, fast-changing technologies on the nanoproducts front have created fast response from the industries. The literature review indicates the absence of any contribution in the area of selection of nanoactuator elements. An attempt has been made by using TOPSIS method, which has a high potential to solve nanoactuator elements selection problem. The paper presents a representative nanoactuator elements database and a transparent assessment procedure, which help the completion of the selection process by focusing on efficiency and consistency. The methodconsiders all the issues of product design right from the conceptual stage till disposal including all the intermittent processes. The relative importance of different attributes of nanoactuator elements for different applications is considered. TOPSIS is more appropriate for optimum selection of nanoactuator elements in order to design and develop nanoproducts/nanodevices as most of the design, production and material attributes are specified / known. The method also ensures that optimally selected/chosen alternative is as close to ideal solution as possible, and as far from the negative ideal solution as possible.

II. IDENTIFICATION OF PERTINENT ATTRIBUTES

In order to design/build an optimum nanoactuators understanding of inherent attributes, properties, strengths, and weaknesses of nanoactuator elements are required. For this, nanoactuators need to satisfy certain performance requirements for a set of applications to work efficiently. There are various nanoactuator elements (like, Slider, Motor stages, racks, sensors, Legs, Guiding grooves, etc.) available in the market for manufacturing and designing of nanoactuators for industrial purposes. Proper identification of attributes of nanoactuator elements is critically important, when comparing various alternative nanoactuator elements and selects the best one for designing nanoactuators. Therefore, whenever a nanoactuators user goes to the supplier for the purchase of new nanoactuators, this identification of attributes attains significant importance. Sometimes, mere articulation of what attributes are important in the context of particular alternatives under consideration leads to a rational choice without formal application of some quantitative or semi-quantitative methodology. However, in most cases, the user needs to be assisted in identifying the attributes of nanoactuator elements wisely and accordingly as per the applications. The final nanoactuator of the industry directly depends upon the proper choice of nanoactuator elements, which are also used for designing of nanoactuators. So, the nanoactuator elements have to be selected with proper identification of attributes. If the identification of attributes is done carefully, then due to this selection of nanoactuator elements for particular application become precise and boosts the productivity.

2.1. Quantification and measurement of the attributes

The nanoactuator elements are expressed in detailed manner with the attributes identified, e.g. close loop travel range 20μm, close loop resolution 0.1nm, resonant frequency 208 KHz, etc. But some of the attributes are not quantitative, e.g. Direction of motion, stick-slip effect, etc. The nanoactuator elements are rated on the common scale of 0-5 for these attributes.

A similar approach has to be used for the informative attributes, which just tell information about some attributes of the nanoactuator elements, such as ruby hemisphere of the nanoactuator elements or behaviour of nanoactuator elements, etc. which is denoted by some number whose numerical value has no significance. It cannot be used for the mathematical treatment, since it is just a numeric representation. There are some attributes of which quantification is not readily available and has to be done by some mathematical modelling, simulation, and analysis. In many cases, the manufacturer make it a standard practice to identify, quantify, and provide these attributes and is also helpful to nanoactuator designers, manufacturers, industrialists, and users, etc.

2.1.1. Usefulness to the manufacturers

The quantification and monitoring of the attribute magnitudes helps the manufacturers to control them closely to fulfil the demand of the users precisely. Moreover, it also helps to find out the market trends by observing the attributes magnitude. It helps the manufacturers to modify their nanoproducts to suit for future needs of the nanoactuator users. The data is used to produce optimum nanoactuators in a minimum possible time. The nanoactuator manufacturers also use these attributes for SWOT (Strength-Weakness-Opportunity-Threat) analysis of his nanoproducts/nanodevices.

2.1.2. Usefulness to the designers

For the designer at conceptual design stage, identification of attributes helps to generate various alternative designs, which are developed as modular nanoactuators. Using the modular nanoactuators approach, the optimum nanoactuator elements are selected according to the market requirements and are designed in short time. The critical attributes, which directly affects the performance are identified. The designer changes these critical attributes and monitors them to control their particular parameters, so that the required performance is obtained from the nanoactuators. Designers use these attributes during cause and effect analysis, and finds out the effects of manipulating these attributes on the nanoactuators performance.

2.1.3. Usefulness to the users

Identification of the attributes helps the user for data storage and their retrieval. The computerized data is generated in different formats for different purposes by different peoples in the organization. It helps the user to select the best possible nanoactuator elements for the particular application, whenever it is required. Keeping the short term and long term objectives in mind comprehensive SWOT analysis by the designers, device manufacturers, and R & D organizations helps in the development of creative and innovative nanodevices/nanoproducts.

2.2. Coding Scheme

The pertinent attributes for optimum selection of nanoactuator elements is identified on the basis of broad categories as: actuation, modelisation, realization, and performance. These broad categories of attributes are useful for storage, retrieval, designing, manufacturing, evaluation, ranking, and optimum selection of nanoactuator elements for R & D of different nanodevices as shown in **Table 1.**

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Actuation										
Travel Range	1	Step size	2	Guiding elements	3	Legs	4	Magnetotrictive	5	Equilibrium positions
	6	Motor stage	7	Direction						
Accumulation	8	Driving leg	9	Rack	10	Direction of motion	11	Anti-recoil leg	12	Elongation
	13	Crawling	14	Forward shift						
Amplification	15	Inertia drive	16	Mechanical	17	Series	18	Piezoelectric	19	Motor stage
	20	Stick capacity								
Force	21	Force capacity	22	Electrostrictive	23	Close loop Resolution	24	Static charges	25	Maxwell force
Modelisation										
Mechanical Aspect	26	Ruby hemisphere	27	Resonant frequency	28	Velocity step	29	Mechanical behaviour	30	Friction coefficient
	31	Static signal stiffness	32	Operating temp						
Thermal Aspect	33	Loading/unloading								
System Displacement	34	Close loop travel range	35	Static friction	36	Shifted mass	37	Speed of system	38	Field forces
	39	Lorentz force	40	Resistive friction force	41	Elongation	42	Slipping	43	Saw tooth signal
Electrical Aspect	44	Variable frequency	45	Cycle ratio	46	Mechanical power				
Realization										
Motion Transmission	47	Fluid motion	48	Magnetic content	49	Cylinder	50	Piezo shear mode	51	Elastic deformation
Control Parameters	52	Step loss	53	Slider mass	54	Surface irregularities	55	Inertia drive	56	Impact mass
	57	Stiffness	58	Surface profile	59	Degree of freedom				
Guiding Aspect	60	Variable gap	61	Casing maintenance						
Performance										
Positioning System	62	Repeatability	63	Kinematic friction force	64	Periodic time	65	Time duration	66	Integrated sensors
Driving Aspect	67	Power supply								
Power Balance	68	Inertia drive	69	Dielectric loss factor	70	Noise	71	Connections	72	Delivered power
	73	Working force	74	Resolution						
Topology	75	Torque	76	Emf distribution	77	Axial loading	78	Packing	79	Electrical reluctance
	80	Field forces	81	Surface irregularities						

Table-1 List of broad categories attributes of nanoactuator elements

The above mentioned attributes are tabulated in the form of 81-digit coding scheme for characterization of nanoactuator elements as shown in **Table 2.**

Actuation					
Travel Range	**1**	**2**	**3**	**4**	**5**
	6	**7**			
Accumulation	**8**	**9**	**10**	**11**	**12**
	13	**14**			
Amplification	**15**	**16**	**17**	**18**	**19**
	20				
Force	**21**	**22**	**23**	**24**	**25**
Modelisation					
Mechanical Aspect	**26**	**27**	**28**	**29**	**30**
	31	**32**			
Thermal Aspect	**33**				
System Displacement	**34**	**35**	**36**	**37**	**38**
	39	**40**	**41**	**42**	**43**
Electrical Aspect	**44**	**45**	**46**		
Realization					
Motion Transmission	**47**	**48**	**49**	**50**	**51**
Control Parameters	**52**	**53**	**54**	**55**	**56**
	57	**58**	**59**		
Guiding Aspect	**60**	**61**			
Performance					
Positioning System	**62**	**63**	**64**	**65**	**66**
Driving Aspect	**67**				
Power Balance	**68**	**69**	**70**	**71**	**72**
	73	**74**			
Topology	**75**	**76**	**77**	**78**	**79**
	80	**81**			

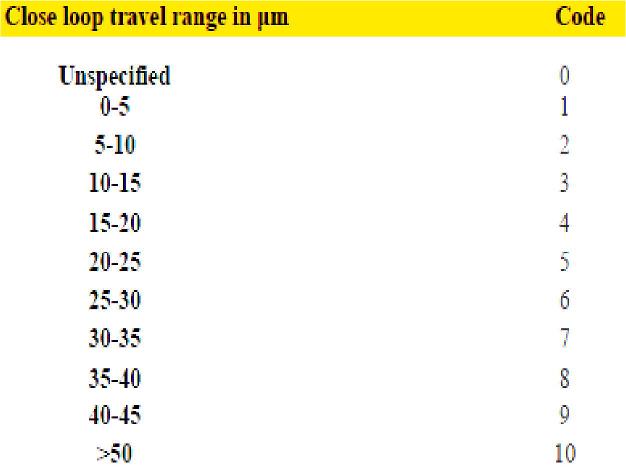
Table-2 81-digit coding scheme for characterization of nanoactuator elements

2.3. Illustration of Coding

The proposed coding scheme explained above is illustrated here with example. Suppose, in order to codifying the close loop travel range of nanoactuator element (motor stages), it is done as follows

2.3.1. Close loop travel range of nanoactuator elements

The close loop travel range for motor stages are coded as shown in **Table-3.**



Close loop travel range in µm	Code
Unspecified	0
0-5	1
5-10	2
10-15	3
15-20	4
20-25	5
25-30	6
30-35	7
35-40	8
40-45	9
>50	10

Table-3 Coding of close loop travel range of nanoactuator element (motor stages)

These codes are used to specify the close loop travel range of motor stages in the respective shell number ‘34’, since it is allotted to it, as shown in Table 4 and Table 5. Here, the motor stage under consideration has the close loop travel range of 20µm, which is given a code of 4.

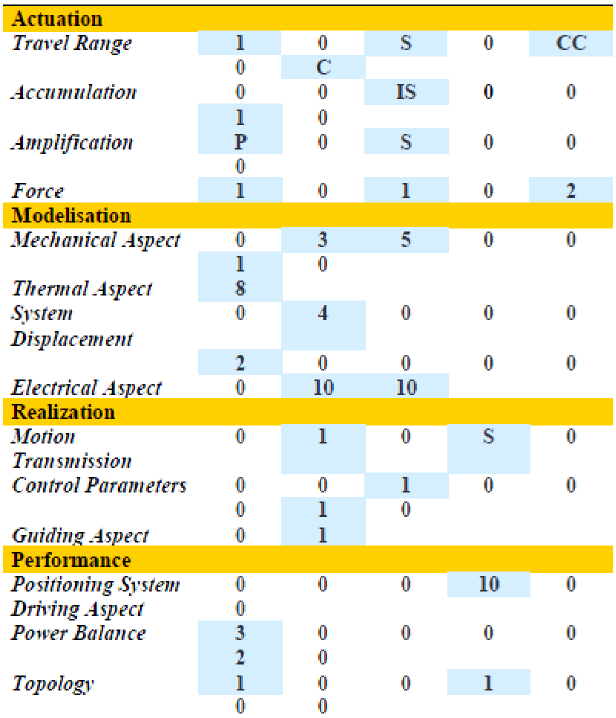
Example of ‘coding scheme for standard nanoactuator element (Motor stage M-661.4P0) are shown in Table 4.

The table clearly indicates that the information supplied by the manufacturer to the user is meagre and it is required to be more elaborate.

Here, most of the cells having 0 as code in them. The 0 represents that the information relating to the particular cell is not available to the authors. The information is not provided by the manufacturer, but the authors think that this information needs to be provided to make the database exhaustive. The coding scheme is also used for visual comparison between two nanoactuator elements (Motor stages) up to the certain extent. It allows faster comparison in various formats. Moreover due to this, data storage, retrieval and the selection procedure is more precise and accurate. Tabular representation of coding scheme for standard nanoactuator element (Motor stage M-661.4P0) is shown in **Table 5**.

S/No	Attributes	Information	Codes
1	Step size	0.1µm	1
2	Guiding elements	-	0
3	Legs	Single/Multi-piece	S
4	Magnetotrictive	-	0
5	Equilibrium positions	Concentric at centre	CC
6	Motor stage	-	0
7	Direction	Clockwise/Anti-clockwise	C
8	Driving leg	-	0
9	Rack	-	0
10	Direction of motion	In the slider direction	IS
11	Anti-recoil leg	-	0
12	Elongation	-	0
13	Crawling	2 µm	1
14	Forward shift	-	0
15	Inertia drive	Positive	P
16	Mechanical	-	0
17	Series	Stable in series	S
18	Piezoelectric	-	0
19	Motor stage	-	0
20	Stick capacity	-	0
21	Force capacity	3N	1
22	Electrostrictive	-	0
23	Close loop Resolution	0.1 µm	1
24	Static charges	-	0
25	Maxwell force	4±1N	2
26	Ruby hemisphere	-	0
27	Resonant frequency	0.5-300Hz	3
28	Velocity step	40-800mm/sec	5
29	Mechanical behaviour	-	0
30	Friction coefficient	-	0
31	Static signal stiffness	2N/ µm	1
32	Operating temp	+10 to +40 ℃	8
33	Loading/unloading	-	0
34	Close loop travel range	20 µm	4
35	Static friction	-	0
36	Shifted mass	-	0
37	Speed of system	-	0
38	Field forces	5N	2
39	Lorentz force	-	0
40	Resistive friction force	-	0
41	Elongation	-	0
42	Slipping	-	0
43	Saw tooth signal	-	0
44	Variable frequency	~208KHz	10
45	Cycle ratio	>107	10
46	Mechanical power	-	0
47	Fluid motion	0.1 µm	1
48	Magnetic content	-	0
49	Cylinder	Single	S
50	Piezo shear mode	-	0
51	Elastic deformation	-	0
52	Step loss	-	0
53	Slider mass	0.2 Kg	1
54	Surface irregularities	-	0
55	Inertia drive	-	0
56	Impact mass	-	0
57	Stiffness	2N/ µm	1
58	Surface profile	-	0
59	Degree of freedom	-	0
60	Variable gap	0.32 µm	1
61	Casing maintenance	-	0
62	Repeatability	-	0
63	Kinematic friction force	-	0
64	Periodic time	107 Cycles	10
65	Time duration	-	0
66	Integrated sensors	-	0
67	Power supply	+12V	3
68	Inertia drive	-	0
69	Dielectric loss factor	-	0
70	Noise	-	0
71	Connections	-	0
72	Delivered power	8.5V	2
73	Working force	-	0
74	Resolution	0.1 µm	1
75	Torque	-	0
76	Emf distribution	-	0
77	Axial loading	0.5 Kg	1
78	Packing	-	0
79	Electrical reluctance	-	0
80	Field forces	-	0
81	Surface irregularities	-	0

Table-4 Coding scheme for standard nanoactuator element (Motor Stage-M-661.4P0)



Actuation					
Travel Range	1	0	S	0	CC
	0	C			
Accumulation	0	0	IS	0	0
	1	0			
Amplification	P	0	S	0	0
	0				
Force	1	0	1	0	2
Modelisation					
Mechanical Aspect	0	3	5	0	0
	1	0			
Thermal Aspect	8				
System	0	4	0	0	0
Displacement					
	2	0	0	0	0
Electrical Aspect	0	10	10		
Realization					
Motion	0	1	0	S	0
Transmission					
Control Parameters	0	0	1	0	0
	0	1	0		
Guiding Aspect	0	1			
Performance					
Positioning System	0	0	0	10	0
Driving Aspect	0				
Power Balance	3	0	0	0	0
	2	0			
Topology	1	0	0	1	0
	0	0			

Table-5 Tabular representation of coding scheme for standard nanoactuator element (Motor Stage-M-661.4P0)

III. 3-STAGE OPTIMUM SELECTION PROCEDURE

The procedure permits faster convergence to optimum nanoactuator elements for given application.

3.1. Stage-1 Elimination Search Method

All the attributes are not equally important, while selecting the nanoactuator elements (Motor Stages) for particular application. There are few attributes, which have direct effect on the selection procedure. Pertinent attributes as necessitated by the particular application and/or the user are identified. The threshold values to these 'pertinent attributes' are assigned by obtaining information from the user and the group of experts. Henceforth, the selection procedure focuses solely on the pertinent attributes leaving out the rest. On the basis of the threshold values of the pertinent attributes, a shortlist of nanoactuator element (Motor Stages) is obtained, which satisfies minimum, maximum, and target values of the pertinent attributes. To facilitate that search procedure an identification system has been made for all nanoactuator elements (Motor Stages) in the data.

3.2. Stage-2 Evaluation Using TOPSIS Method

A mini-database is thus formed, which comprises these satisfying solutions, i.e. alternatives which have all the attributes satisfying the acceptable levels of aspiration. The problem is now to find out the (optimum or best) out of these satisfying solutions. The selection procedure therefore needs to rank these solutions in order of merit. It consists of following steps as shown below:-

Step:-1. Data/Decision matrix, D = [dij]m x n

The first step is to represent all the information available from the data about these satisfying solutions in the matrix form. Such a matrix is called decision matrix 'D' [d_{ij}]. Each row of the matrix is allocated to one candidate nanoactuator element (Motor Stage) and each column to one attribute under consideration. An element 'd_{ij}' of the decision matrix D gives the value of j^{th} attribute in the row (non-normalized) form and units for the i^{th} nanoactuator elements. Thus if the number of short-listed nanoactuator element (Motor Stages) is 'm' and the number of pertinent attributes is 'n' the decision matrix is an 'm x n' matrix.

Step:-2.Normalized specifications matrix, N = [nij]m x n

The second step is the construction of normalized specification matrix, 'N' [N_{ij}] from the decision matrix D. Normalization is used to bring the data within particular range 0 to 1 and moreover, it provides the dimensionless magnitudes. The phenomenon is used to calculate the normalized specification matrix. The normalized specification matrix has the magnitudes of all the attributes of the nanoactuator element (Motor Stages) on the common scale of 0 to 1. It is a sort of value, which indicates the standing of that particular attributes magnitude, when compared to the whole range of the magnitudes for all candidate nanoactuator elements (Motor Stages). An element n_{ij} of the normalized matrix N is calculated as:-

$$n_{ij} = \frac{d_{ij}}{\sqrt{\sum_{i=1}^{m} d_{ij}^{2}}} \qquad (1)$$

Step:-3. Relative Importance Matrix, A = [aij]n x n

The third step is to obtain information from the user or the group of experts, on the relative importance of one attribute with respect to another. The information is sought in terms of a ratio. Information on all such pair-wise comparisons is stored in a matrix called as relative importance matrix 'A' [a_{ij}], which is 'n x n' matrix. Here 'a_{ij}' contain the relative importance of i^{th} attribute over the j^{th} attribute. The symmetric terms of the matrix are reciprocals of each other, while the diagonal elements are unity. The information stored in matrix 'A' is on pair-wise basis. It is modified into representation that gives the relative weights of all attributes taken together, so that the cumulative sum of the weights is equal to unity.

Step:-4. Weight vector, W = [w_1, w_2, w_3, w_n]^T

The Eigen vector method is used, which modifies inconsistencies in the judgement of relative importance of attributes, while making pair-wise comparisons and is used to find out the weights. These inconsistencies arise due to inaccurate human judgments [34]. The Eigen vector method seeks to find weight vector 'W' from the Eigen value problem associated with the matrix 'A'. If,

$$W = \begin{bmatrix} W_1 \\ W_2 \\ \\ \\ W_5 \end{bmatrix} \qquad A = \begin{bmatrix} a_{11} & a_{12} & . & a_{1n} \\ a_{21} & a_{22} & . & a_{2n} \\ . & . & . & . \\ . & . & . & . \\ . & . & . & . \\ a_{n1} & a_{n2} & . & a_{nn} \end{bmatrix}$$

Then the linear transformation Y = AW (2)

It transforms the column vector 'W' into the column vector 'Y' by means of the square matrix 'A'. In practice, it is often required to find such vectors which transform them into themselves or to a scalar multiple of themselves.

Let, W be such a vector which transforms them into λW by means of the transformation equation. Then, A W= λW or AW - λIW = 0 or

$$(A - \lambda I)\, W = 0 \qquad (3)$$

Where, 'λ' is the Eigen value of 'A' and 'W' is the corresponding Eigen vector [35]. For 'n x n A' there are 'n' Eigen values λ_I (for i = 1, n,) and corresponding to λ_i, there are 'n' Eigen values. Vector 'W' is now found in the following manner. The Equation (3) is also called Eigen value formulation that provides to find out the weight vector as shown below:-

(A - λ I) W = 0, Where, I is the identity matrix, and W is the weight vector. The Equation (3) is also written as

$$(A - \lambda I) = 0 \text{ and } W = 0, \qquad (4)$$

Where W = 0, gives a trivial solution having no meaning.

Take Eigen weight vector, W corresponding to the largest Eigen value λ_{max}, as all the elements of λ are either positive or negative [34]. In that way, maximum Eigen value is calculated by using Equation (4). In order to find out the weights for each attribute using Eigen vector associated with maximum Eigen value is calculated by using Equation (5) as:-

$$(A - \lambda_{max} I)\, W = 0 \qquad (5)$$

In this summation of weight vectors W_i is given as:-

$$\sum_{i=1}^{n} w_i = 1 \qquad (6)$$

$$W_1+W_2+W_3+W_4+W_5 = 1 \qquad (7)$$

Step:-5.Weighted normalized specification matrix, $V = [v_{ij}]_{m \times n}$

The weights obtained from the relative importance matrix have to be applied to the normalized specifications, since all the attributes have different importance, while selecting the nanoactuator element (Motor Stages) for particular application. The matrix, which combines the relative weights and normalized specification of the candidates, is weighted normalized matrix, ‘V’. It gives the true comparable values of the attributes and is obtained as follows:-

$$v_{ij} = w_j \, . \, Nij, \; i = 1, m \text{ and } j = 1, n \qquad (8)$$

The positive-ideal (best) solution of nanoactuator element (Motor Stages) is expressed as:-

$$\begin{aligned} V^+ &= \left\{ \left(\sum_i^{\max} V_{ij} / j \in J \right), \left(\sum_i^{\min} V_{ij} / j \in J' \right) / \; i = 1,2, \ldots\ldots N \right\} \\ &= \{V_1^+, \; V_2^+, V_3^+, V_4^+, \ldots\ldots\ldots, V_M^+\} \end{aligned} \qquad (9)$$

The Negative-ideal (worst) solution of nanoactuator element (Motor Stages) is expressed as:-

$$\begin{aligned} V^- &= \left\{ \left(\sum_i^{\min} V_{ij} / j \in J \right), \left(\sum_i^{\max} V_{ij} / j \in J' \right) / \; i = 1,2, \ldots\ldots N \right\} \\ &= \{V_1^-, \; V_2^-, V_3^-, V_4^-, \; \ldots\ldots\ldots, V_M^-\}, \end{aligned} \qquad (10)$$

Where J = (j=1,2,3……,M) / j is associated with beneficial attributes, and J’=(j=1,2,3……,M) / j is associated with non-beneficial attributes. The alternative V^+ indicates the most preferable alternative or the ideal solution. Similarly, alternative V^- indicates the least preferable alternative or the negative-ideal solution.

3.3. Ranking and selection procedure

The ranking of the nanoactuator elements (motor stages) are done either mathematically (TOPSIS method) or graphically (Line graph and spider diagram methods).

3.3.1. TOPSIS method

The weighted normalized matrix V is used to obtain the +ve and -ve benchmark nanoactuator element (Motor Stages), where both the benchmark nanoactuator element are hypothetical nanoactuator element , which supposed to have best and worst possible attribute magnitudes. The TOPSIS method is based on the concept that the chosen option (optimum) have the shortest distance from the +ve benchmark nanoactuator element (Motor Stages) (best possible nanoactuator element (Motor Stages)) and farthest from the -ve benchmark nanoactuator element (Motor Stages) (worst possible nanoactuator element (Motor Stages)). The measure ensures that the top ranked nanoactuator element (Motor Stages) is closest to +ve benchmark nanoactuator element (Motor Stages) and farthest from -ve benchmark nanoactuator element (Motor Stages). The calculations are made on separation measures from +ve and - ve benchmark nanoactuator element (Motor Stages), respectively, as S_i^+ and S^-_i

The separation of candidates from the +ve benchmark nanoactuator element (Motor Stages) is given by:-

$$S_i^+ = \left\{ \sum_{j=1}^{n} (V_{ij} - V_j^+)^2 \right\}^{0.5}; \qquad (11)$$

$$j = 1, 2, \ldots, n; \quad i = 1, 2, \ldots, m$$

Separation of candidates from the -ve benchmark nanoactuator element (Motor Stages) is given by:-

(12)

Then, the relative closeness of candidates to the +ve benchmark nanoactuator element (Motor Stages), C_i*, (which is a measure of the suitability of the nanoactuator element (Motor Stages)) for the chosen application on the basis of attributes considered, is calculated. A nanoactuator element (Motor Stages) with the largest C_i* is preferable

$$C_i^* = \frac{S_i^-}{S_i^+ + S_i^-} \text{, Where } i = 1, \ldots\ldots\ldots\ldots, m \qquad (13)$$

Ranking of the candidate nanoactuator element (Motor Stages) is done in accordance with the decreasing values of indices C_i*, indicating the most preferred and the least preferred feasible optional solutions, this index is called suitability/goodness/proximity index.

3.3.2. Graphical method

There are many methods to evaluate the nanoactuator element (Motor Stages) using mathematical approach. A graphical method is proposed to process the available data and select the nanoactuator element (Motor Stages). The graphical representation methods, like line graph and spider diagram are used for this purpose.

3.3.2.1. Line graph representation:

The specification matrix D, normalized and weighted normalized specification matrices N and V, respectively are developed, containing information of the candidate nanoactuator elements (Motor Stages). These matrices are represented graphically using line graph by plotting the magnitude of the attributes on the vertical axis and the attributes on the horizontal axis. Minimum values for cost attributes are preferred. The values are plotted for different candidate nanoactuator elements (Motor Stages) to obtain the line graph for them. These graphs are distinct for all candidate nanoactuator elements (Motor Stages) and used for comparison.

The area under the curve used for quantification purpose and to compare the candidate nanoactuator elements (Motor Stages) with each other. **Figure-1** Represents the line graph plot for evaluation and ranking of nanoactuator element (Motor Stages).

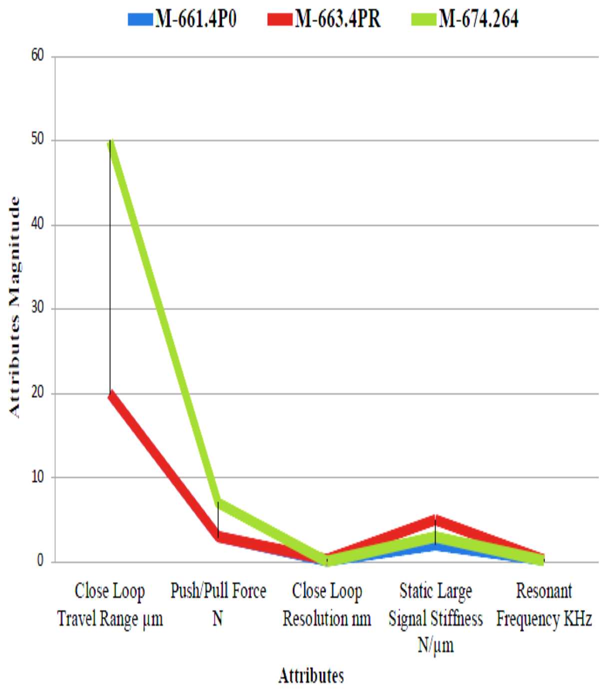


Fig.-1 Represents the line graph plot for evaluation and ranking of nanoactuator element (Motor Stages).

The line graphs are plotted for specifications, normalized and weighted normalized specification of all candidate nanoactuator elements (Motor Stages) as well as the benchmark nanoactuator elements (Motor Stages). The area under the curve is obtained as follows.

Let the width between the two parameters on horizontal axis as unity and d_{ij}, n_{ij}, and v_{ij} are the elements of D, N, and V matrices.

Area under the line graph of specification of ith nanoactuator elements (Motor Stages) found out as:-

$$\mathrm{AD}_i^L = (d_{i,1} + 2(d_{i,2} + \cdots + d_{i,n-1}) + d_{i,n})/2 \tag{14}$$

Similarly, area under the line graph of normalized and weighted normalized specifications of the i^th^ nanoactuator elements (Motor Stages), i.e. $\mathrm{AN}^{\mathrm{Li}}$ and $\mathrm{AV}^{\mathrm{Li}}$ using their respective elements are obtained.

***3.3.2.2. Spider diagram*:** In this method, the attributes have been considered to be forming the spider diagram. So that the angle θ between the attribute axes are calculated as θ = 2π/n, where n is the number of attributes under consideration.

$$\mathrm{AD}_i^S = \frac{\sin\theta}{2}\sum_{j=1}^{n} d_{ij}d_{i,j+1}; \quad \text{where } d_{i,n+1} = d_{i,1}.$$

The attributes, normalized and weighted normalized specifications magnitudes are plotted to obtain the spider diagram, also known as polar or radar diagram, as shown in Figure 2 for different candidate nanoactuator elements (Motor Stages).

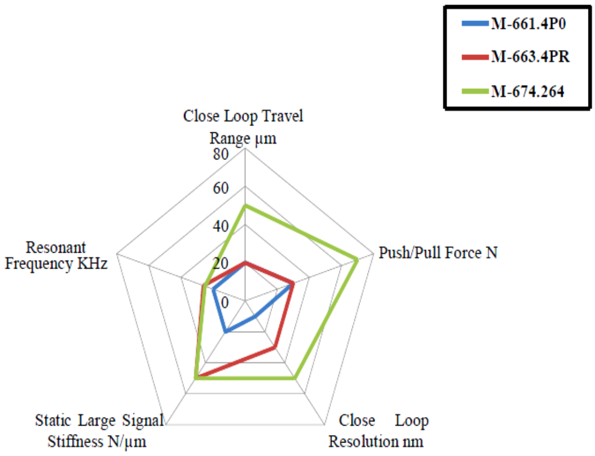


Fig. 2 Spider diagram polygon for candidate nanoactuator element (Motor Stages).

Here, the area enclosed by the polygon formed on the spider diagram is the indication of the nanoactuator element capabilities. All the specification magnitudes are boiled down to this single index. The area enclosed by the polygon of the i^th^ nanoactuator elements (Motor Stages) is calculated as follows.

In the spider diagram, θ = 2π/n, where n is the number of attributes.

Let, d_{ij} represents the value of j^th^ attribute in the i^th^ nanoactuator element (Motor Stages) along θ_i.

Let, n_{ij} represents the normalized value of the j^th^ attribute in the i^th^ nanoactuator element along θ_i.

Let v_{ij} represents the weighted normalized value of the j^th^ attribute in the i^th^ nanoactuator element (Motor Stages) along θ_i.

Similarly, for normalized and weighted normalized specifications areas enclosed by polygons, i.e. $\mathrm{AN}^{\mathrm{Si}}$, $\mathrm{AV}^{\mathrm{Si}}$, respectively, are calculated.

3.3.2.3. Identification and graphical representation of the benchmark nanoactuator element: (Motor Stages).

The same +ve benchmark nanoactuator elements (Motor Stages), defined earlier, is used here for comparison and ranking of candidate nanoactuator elements (Motor Stages). The areas under the line graph for +ve benchmark nanoactuator element (Motor Stages), i.e., $\mathrm{AD}^{\mathrm{LB}}$, $\mathrm{AN}^{\mathrm{LB}}$, $\mathrm{AV}^{\mathrm{LB}}$ are also calculated. The areas enclosed by the polygon of spider diagram for benchmark nanoactuator element (Motor Stages), i.e. $\mathrm{AD}^{\mathrm{SB}}$, $\mathrm{AN}^{\mathrm{SB}}$, $\mathrm{AV}^{\mathrm{SB}}$ are also calculated. All candidate nanoactuator elements (Motor Stages) are compared with the +ve benchmark nanoactuator elements (Motor Stages) for the evaluation purpose. It shows the suitability of the nanoactuator elements (Motor Stages) for the particular task.

3.3.2.4. Ranking and selection of the nanoactuator element (Motor Stages):

Now, the specification matrix is used along with normalized specification and weighted specification matrices of all candidate nanoactuator elements (Motor Stages) along with

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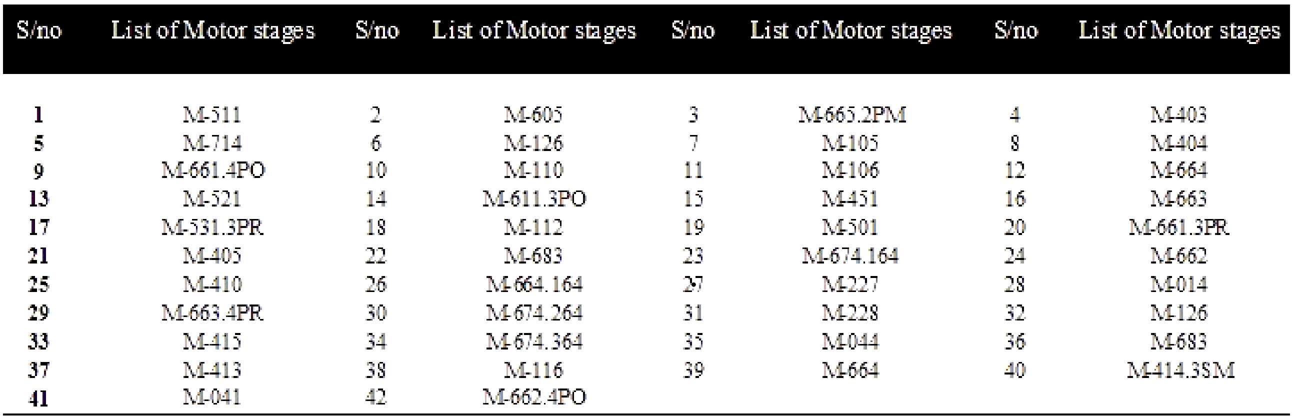
the +ve benchmark nanoactuator element (Motor Stages). There is a need to measure and compare the candidate nanoactuator elements (Motor Stages) with benchmark nanoactuator elements (Motor Stages) for ranking and optimum selection.

3.2.5.Coefficient of similarity (COS):

The evaluation and ranking of the nanoactuator element (Motor Stages) using the novel graphical methods are done by their similarity to +ve benchmark nanoactuator elements (Motor Stages). Let, the Coefficient of similarity (COS) be the ratio of area under the curve or enclosed by the polygon for the candidate to that of the benchmark nanoactuator element (Motor Stages). The value of COS is any +ve fraction (0 □COS □ 1) and a measure of the closeness of candidate nanoactuator element (Motor Stages) with the benchmark nanoactuator element (Motor Stages).

Table-6 List of 42 standard motor stages



S/no	List of Motor stages	S/no	List of Motor stages	S/no	List of Motor stages	S/no	List of Motor stages
1	M-511	2	M-605	3	M-665.2PM	4	M-403
5	M-714	6	M-126	7	M-105	8	M-404
9	M-661.4PO	10	M-110	11	M-106	12	M-664
13	M-521	14	M-611.3PO	15	M-451	16	M-663
17	M-531.3PR	18	M-112	19	M-501	20	M-661.3PR
21	M-405	22	M-683	23	M-674.164	24	M-662
25	M-410	26	M-664.164	27	M-227	28	M-014
29	M-663.4PR	30	M-674.264	31	M-228	32	M-126
33	M-415	34	M-674.364	35	M-044	36	M-683
37	M-413	38	M-116	39	M-664	40	M-414.3SM
41	M-041	42	M-662.4PO				

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The candidates with COS magnitude closer to unity are preferable, since it indicates the closeness to the +ve benchmark
nanoactuator element (Motor Stages).

According to TOPSIS method

COS = (C_i* - 0), COS^D = (1- C_i*), and

COS +COS^D= (C_i* - 0) + (1- C_i*) = 1.

Coefficient of similarity (COS) based on decision matrix

$$\mathrm{COS}_j^D = \mathrm{AD}_j/\mathrm{AD}_I \qquad (15)$$

AD_j and AD_I are the areas under the line graph of specifications for j^{th} and i^{th} nanoactuator elements (Motor Stages).Coefficient of similarity (COS) based on normalized specifications matrix

$$\mathrm{COS}_j^N = \mathrm{AN}_j/\mathrm{AN}_I \qquad (16)$$

AN_j and AN_I are the areas under the line graph of normalized specifications for ^{jth} and i^{th} nanoactuator elements (Motor Stages).

Coefficient of similarity (COS) based on weighted normalized matrix

$$\mathrm{COS}_j^V = \mathrm{AV}_j/\mathrm{AV}_I \qquad (17)$$

AV_j and AV_I are the area under the line graph of weighted normalized specifications for j^{th} and i^{th} nanoactuator elements (Motor Stages).

Thus, the COS calculations for all the ‘n’ number of candidate nanoactuator elements (Motor Stages) are done by graphical methods, viz., line graph and spider diagram methods using the weighted normalized specifications. Though the COS based on the specifications and normalized specifications were also calculated, but it is not significant from the selection point of view. It indicates how the preferences changed during the normalization and weight application process. It is also used for monitoring the process.

IV. ILLUSTRATIVE EXAMPLE

Here, the illustrative example for the ranking and optimum selection of nanoactuator elements (Motor Stages) based on TOPSIS and graphical methods is presented. Scientists, engineers and product Developers may also use this following example for implementation of proposed methodology.

The steps involved in ranking and optimum selection of nanoactuator elements (motor stages) for designing nanoactuators as per the considered application are shown below:-

Stage-1.Elimination Search Method

Identify, the application and corresponding pertinent attributes. Define the requirements of research and product development carefully. Eliminate the large list of nanoactuator elements (Motor Stages) to a manageable list. The short-listed alternatives are obtained from different

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design teams/experts or as suggested by vendors. In actual practice, a large number of nanoproducts its subsystems, e.g. actuators, motor stages are available as possible candidate for selection of alternatives. Short listingof alternatives are done for the application of "designing a nanoactuators for high-resolution positioning" for which optimum selection of nanoactuator elements (i.e. motor stages) is most important.

So, list of 42 standard motor stages and their data have been collected through internet website for selection and ranking of nanoactuator elements (motor stages) as per the given application as shown in **Table 6.**

Out of these 42 standard motor stages list of only 6 motor stages with their 5 specifications are best suited for the given application and remaining motor stages are eliminated on the basis of requirements which does not meet as required by the given application. The specifications such as: stick slip effect, direction of motion, friction coefficient, shear force limit, etc. are supported by all the short listed motor stages and some are omitted during ranking and selection of motor stages as per the considered application. The attributes for the short listed alternative nanoactuator element (Motor Stages) are shown in **Table 7.**

Table 7. Attributes for short listed alternative nanoactuator element (motor stages)

Attributes of short listed alternatives

Candidate motor stages	Close loop Travel range µm	Push/Pull force N	Close loop resolution nm	Static large signal stiffness N/µ m	Resonant frequency kHz
M-661.4P0 (M_1)	20	3	0.1	2	208
M-662.4P0 (M_2)	19.5	2	0.2	3	198
M-663.4PR (M_3)	20	3	0.3	5	268
M-664.164 (M_4)	25	4	0.1	3	212
M-665.2PM (M_5)	50	5	0.1	4	274
M-674.264 (M_6)	50	7	0.05	5	155

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The selection of nanoactuator element (motor stages) would be done using (TOPSIS Technique). **Figure 3** shows a flowchart of the TOPSIS technique.MADM methods choose or rank finite number of alternatives that are measured by few relevant attributes. TOPSIS is the technique used to rank these alternatives in the presence of multiple attributes representing a candidate nanoactuator element (Motor Stages).

Stage-2.Evaluation using TOPSIS method

Step:-1. Data/Decision matrix, D = [d_{ij}]$_{m \times n}$

It is an information matrix, where each row represents 'm' number of short listed alternatives-motor stages alternatives, and columns represent 'n' number of pertinent attributes viz. close loop travel range and static large signal stiffness, etc. as shown in Table7. The example considers 6 candidate motor stages and 5 specifications as shown below:-

$$D = \begin{bmatrix} 20 & 3 & 10 & 2 & 208 \\ 19.5 & 2 & 5 & 3 & 198 \\ 20 & 3 & 3.3 & 5 & 268 \\ 25 & 4 & 10 & 3 & 212 \\ 50 & 5 & 10 & 4 & 274 \\ 50 & 7 & 20 & 5 & 155 \end{bmatrix} \quad (18)$$

Step:-2.Normalized specifications matrix, N = [n_{ij}]$_{m \times n}$

Normalization of the attributes is carried out to bring all the attributes having different magnitudes and units in the range of 0 and 1. .

An element n_{ij} of the normalized matrix N is calculated by using Equation (1).

$$N = \begin{bmatrix} 0.2424 & 0.2834 & 0.3686 & 0.2132 & 0.3808 \\ 0.2363 & 0.1889 & 0.1843 & 0.3198 & 0.3625 \\ 0.2424 & 0.2834 & 0.1216 & 0.533 & 0.4906 \\ 0.303 & 0.3779 & 0.3686 & 0.3198 & 0.3881 \\ 0.6061 & 0.4724 & 0.3686 & 0.4264 & 0.5016 \\ 0.6061 & 0.6614 & 0.7372 & 0.533 & 0.2837 \end{bmatrix} \quad (19)$$

Step:-3. Relative Importance Matrix, A = [a_{ij}]$_{n \times n}$

Each application of nanoactuator elements needs different relative importance between attributes. Relative importance between attributes $a_{ij} = w_i/w_j$ are developed for every application under consideration based on pair-wise comparison of attributes. Each element a_{ij} is obtained either by a team of relevant experts of the area or based on the responses of questionnaires and personal discussion with the experts. Relative importance matrix for given application is obtained from team of experts in this example.

$$A = \begin{bmatrix} 1 & 1 & 2 & 0.5 & 0.33 \\ 1 & 1 & 0.5 & 2 & 2 \\ 0.5 & 2 & 1 & 3 & 2 \\ 2 & 0.5 & 0.33 & 1 & 0.33 \\ 3 & 0.5 & 0.5 & 3 & 1 \end{bmatrix} \quad (20)$$

Step:-4. Weight vector, W = [w_1, w_2, w_3, w_n]^T

Eigen value formulation is used to determine weight vector for attributes of nanoactuator elements (motor stages). Eigen value formulation is represented by

$$(A - \lambda I)\, W = 0 \qquad (21)$$

Where, I is the identity matrix and W is the weight vector. Equation (21) is either written as $(A - \lambda I) = 0$ or $W = 0$, but $W = 0$ gives a trivial solution.

$$(A - \lambda I) = \begin{bmatrix} 1 & 1 & 2 & 0.5 & 0.33 \\ 1 & 1 & 0.5 & 2 & 2 \\ 0.5 & 2 & 1 & 3 & 2 \\ 2 & 0.5 & 0.33 & 1 & 0.33 \\ 3 & 0.5 & 0.5 & 3 & 1 \end{bmatrix} = 0 \qquad (22)$$

Determinant expansion of Equation (22) gives nth order characteristics polynomial equation obtained using “MATLAB”.

Characteristics Polynomial Equation

$$- \lambda^5 + 5\lambda^4 - 0.03\lambda^3 + 25.85\lambda^2 + 21.88\lambda + 9.767 = 0$$

The solution of the polynomial gives an Eigen spectrum as $[\lambda_1, \lambda_2, \lambda_3, \lambda_n]$. $\lambda_{max} = 6$ is obtained. The λ_{max} is selected to determine the weight vector (W) from $(A - \lambda_{max} I)\, W = 0$.

Therefore,

$$(A - \lambda_{max} I)\, W = \begin{bmatrix} -5 & 1 & 2 & 0.5 & 0.33 \\ 1 & -5 & 0.5 & 2 & 2 \\ 0.5 & 2 & -5 & 3 & 2 \\ 2 & 0.5 & 0.33 & -5 & 0.33 \\ 3 & 0.5 & 0.5 & 3 & -5 \end{bmatrix} \begin{bmatrix} W1 \\ W2 \\ W3 \\ W4 \\ W5 \end{bmatrix} = 0 \qquad (23)$$

Subject to

$$\sum_{i=1}^{n} w_i = 1$$

The solution of this set of simultaneous equations gives weight vector, $W = [w_1, w_2, w_3, w_n]^T$

$W_1 = 0.1761$, $W_2 = 0.2042$. $W_3 = 0.2668$, $W_4 = 0.2430$, $W_5 = 0.2286$

Step:-5.weighted normalized specification matrix, $V = [v_{ij}]_{m \times n}$

Multiply the columns of the normalized decision matrix by the associated weights. The weighted normalized specification matrix is obtained by using Equation (8) and it is shown below in Equation (24).

$$v_{ij} = w_j \,.\, n_{ij},\ i = 1, m \text{ and } j = 1, n$$

$$V = \begin{bmatrix} 0.0426 & 0.0578 & 0.0983 & 0.0518 & 0.087 \\ 0.0416 & 0.0385 & 0.0491 & 0.0777 & 0.0828 \\ 0.0426 & 0.0578 & 0.0324 & 0.1295 & 0.1121 \\ 0.0533 & 0.0771 & 0.0983 & 0.0777 & 0.0887 \\ 0.1067 & 0.0964 & 0.0983 & 0.1036 & 0.1146 \\ 0.1067 & 0.135 & 0.1966 & 0.1295 & 0.0648 \end{bmatrix} \qquad (24)$$

The weighted normalized specification matrix is all-inclusive matrix, which takes care of the specification values and their relative importance. So the matrix is able to provide good basis for comparison with each other and with the benchmark motor stages.

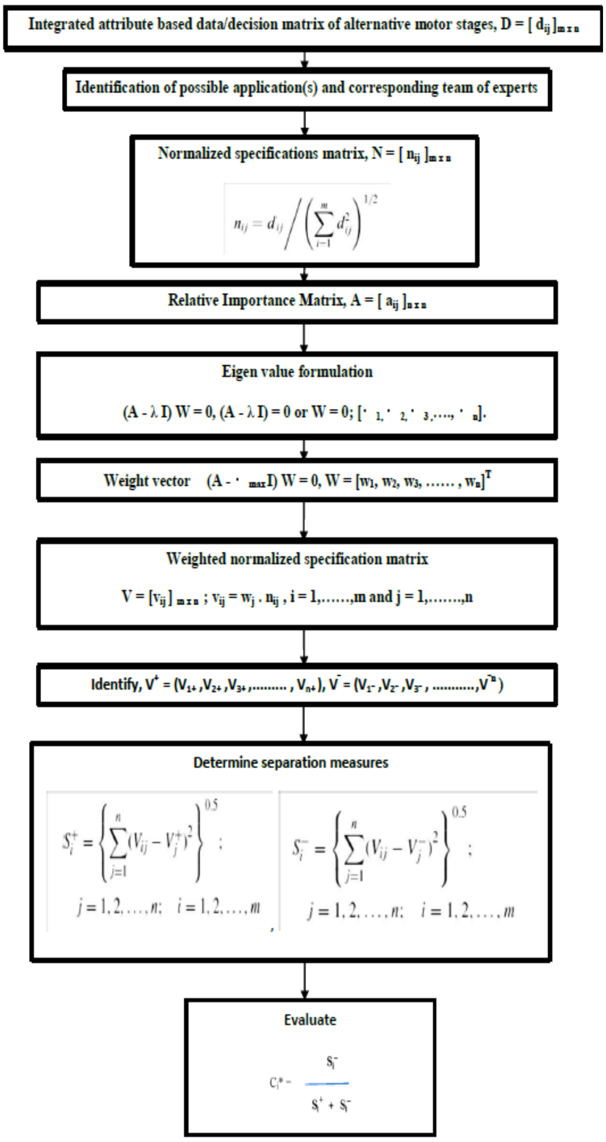


Fig. 3 TOPSIS flow chart

4.1. TOPSIS method for ranking

v+ and v$^-$ are defined from $v = [v_{ij}]$ as positive-ideal (best) solution and negative-ideal (worst) solution of nanoactuator elements (motor stages) and are expressed by Equation (9) and Equation (10).

Therefore, theoretically best solution and worst solution of nanoactuator elements (motor stages) are calculated by using Equation (9) and Equation (10) as shown below:-

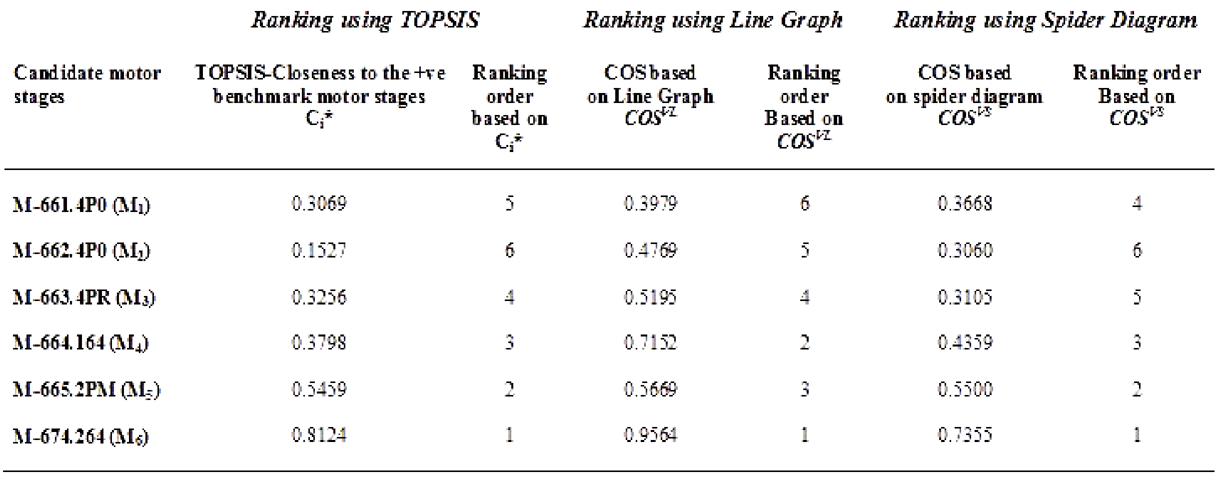
$V^+ = (0.1067, 0.1350, 0.1966, 0.1295, \text{and } 0.1146)$

$v^- = (0.0416, 0.0385, 0.0324, 0.0518, \text{and } 0.0648)$

Every nanoactuator elements (candidates and v+ and v$^-$) is represented n-dimensional attribute hyperspace. Euclidean distances of all the nanoactuator elements (motor stages) are obtained from v$^+$ and v$^-$ as shown in Equations (11 and 12).

The separation of nanoactuator elements (motor stages) v_i from v$^+$ and v$^-$ is given as Euclidean distance shown below:-

$S_i^+ = S^{+1} = 0.1628$, $S^{+2} = 0.1974$, $S^{+3} = 0.1924$, $S^{+4} = 0.1386$, $S^{+5} = 0.1087$, $S^{+6} = 0.0498$ and



	Ranking using TOPSIS		*Ranking using Line Graph*		*Ranking using Spider Diagram*	
Candidate motor stages	TOPSIS-Closeness to the +ve benchmark motor stages C_i^*	Ranking order based on C_i^*	COS based on Line Graph COS^{VL}	Ranking order Based on COS^{VL}	COS based on spider diagram COS^{VS}	Ranking order Based on COS^{VS}
M-661.4P0 (M_1)	0.3069	5	0.3979	6	0.3668	4
M-662.4P0 (M_2)	0.1527	6	0.4769	5	0.3060	6
M-663.4PR (M_3)	0.3256	4	0.5195	4	0.3105	5
M-664.164 (M_4)	0.3798	3	0.7152	2	0.4359	3
M-665.2PM (M_5)	0.5459	2	0.5669	3	0.5500	2
M-674.264 (M_6)	0.8124	1	0.9564	1	0.7355	1

Table 8 Evaluation and ranking of the candidate nanoactuator element (motor stages) using various methods

$S_i^- = S^{-1} = 0.0721$, $S^-_2 = 0.0356$, $S^-_3 = 0.0929$, $S^-_4 = 0.0849$, $S^-_5 = 0.1307$, $S^-_6 = 0.2157$.

Then, the relative closeness to ideal solution C_i^* of nanoactuator elements (motor stages) to v^+ and v^- is defined as

$$C_i^* = \frac{S_i^-}{S_i^+ + S_i^-}\text{, Where } i = 1, \ldots\ldots\ldots, m$$

Where, C_i^* varies in the range of 0 and 1. Ranking of nanoactuator elements (motor stages) for designing nanoactuators in order of preference is obtained by arranging C_i^* in decreasing order. Nanoactuator elements (motor stages) with maximum C_i^* is closest to v^+ and farthest from v^- is considered best nanoactuator elements (motor stages). Therefore, relative closeness to ideal solution C^*_i calculated by using Equation (13) as shown below:-

$C^*_1=0.3069$, $C^*_2=0.1527$, $C^*_3=0.3256$, $C^*_4 = 0.3798$, $C^*_5=0.5459$, $C^*_6 = 0.8124$

All the ranked candidates, C_i^*, i = 1, m, are feasible solutions satisfying all the minimum requirements, constraints, aims and objectives. The ranking of nanoactuator elements (motor stages) based on C_i^* is $C_6^* > C_5^* > C_4^* > C_3^* > C_1^* > C_2^*$. Final selection is carried out based on certain minimum and maximum value of attributes, strength, weakness, opportunities, threats, short term and long term strategies based on R & D and application considerations.

2. Graphical method based ranking

The element values of weighted normalized Specification matrix is used for the line graph or spider diagram plotting. Subsequently, COS is calculated from graphs. The calculated COS is tabulated as follows:-

Suppose, the area under the line graph for weighted normalized specifications of first candidate nanoactuator element (motor stage) and for benchmark nanoactuator element (motor stage) are $AV_{1L} = 0.2727$; $AV_{+BL} = 0.5717$. The coefficient of similarity based on the weighted normalized specification of the first candidate nanoactuator element (motor stage) is:-

$$COS_{1VL} = AV_{1L} / AV_{+BL} = 0.4769 \qquad (25)$$

Evaluation and ranking of the candidate nanoactuator elements (motor stages) using TOPSIS and graphical methods are shown in **Table 8.**

Whereas the TOPSIS method ensures that the selected optimum nanoactuator element (motor stages) is closest to positive benchmark (best) solution and farthest from negative benchmark (worst) solution. Similarly, closeness of the candidate nanoactuator element (motor stages) with the +ve benchmark nanoactuator element (motor stages) obtained from TOPSIS and the graphical methods are tabulated (See Table 8). Thus, the nanoactuator elements (motor stages) are ranked in order of preference based on the attributes selected. For the purchase of new nanoactuator elements (motor stages), the management use the above ranking effectively to select the nanoactuator elements (motor stages), which are best suitable for the application and is based on this set together with other considerations.

V. ROLE OF USER IN SELECTION

Here, the ranking of candidate nanoactuator elements (Motor Stages) done by using TOPSIS and graphical methods vary from each other. Even for both graphical methods the ranking is not same. The user find out which method is best suited for the application under consideration. Thus, the nanoactuator elements (Motor Stages) is ranked in order of preference based on the attributes selected.

However, before a final decision is taken to purchase new nanoactuator elements, the following factors come into picture:-

(1) Economic considerations,
(2) Availability,
(3) Management constraints are corporate policies,
(4) SWOT analysis, (by Keeping the short term and long term objectives in mind), comprehensive SWOT analysis by the designer, device manufacturer and R & D organizations helps in the development of creative and innovative nanodevices,
(5) International market policies, which were not previously considered in coding and evaluation.

Even if the above consideration, say, economic considerations, does not allow the user to buy the top ranked nanoactuator elements (Motor Stages), the user know which one is better accordingly to their need and go for the next choice. For example, 2nd and 3rd ranked nanoactuator elements (Motor Stages) costing the same, but as our result indicates, the 2nd ranked nanoactuator element (Motor

Stages) performs better in other aspects even though their price is same.

Step-by-step procedure for optimum selection of nanoactuator elements

Step-1:- Decide about the aims and objective for which nanoactuator elements is to be used.

Step-2:-Identify all the possible alternative nanoactuator elements available in the literature and global market.

Step-3: Use cause and effect diagram to find out different classes/groups of attributes/properties/ characteristics and different attributes in identified classes.

Step-4:-Develop an n-digit coding scheme for characterization/specification of nanoactuator elements for storage and retrieval in the computer. It helps in in-depth understanding of nanoactuator elements.

Step-5:-Carry out elimination search to reduce the large list of alternatives nanoactuator elements to a manageable list of nanoactuator elements.

Step-6:-Select TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) as attribute based evaluation procedure for this small list of alternatives for ranking.

Step-7:-After evaluation, rank the candidate nanoactuator elements in order of preference for given application.

Step-8:- Final selection by the user from this ranked list based on external considerations.

VI. RESULTS AND DISCUSSION

In actual practice, a large number of nanoproducts, its subsystems, e.g. actuators, motor stages are available as possible candidates for selection. Based on the broad categories of attributes under consideration maximum and minimum values of attributes are identified. Many candidates are not able to satisfy these constraints. To limit the number of nanoactuator elements (Motor Stages) for final evaluation by TOPSIS method few pertinent attributes are identified for further screening limiting the number below 10. Multiple attributes are reduced to single index for ranking purpose. Example clearly shows ranking of six feasible nanoactuator elements (motor stages) for design of nanoactuators based on pertinent attributes. Final selection is based on strategies of thedesigners, researchers, product developers and market needs. It is to be noted that all six nanoactuator elements (motor stages) satisfy every requirements of R & D and then finally chosen. Using TOPSIS method ranking of 6 alternatives is obtained as $M_6 > M_5 > M_4 > M_3 > M_1 > M_2$. It is recommend that nanoactuator element (motor stage) alternative M_6, i.e. M-674.264 is the first choice, and M-665.2PM, M-664.164, M-663.4PR, M-661.4P0 and M-662.4P0 are placed in the second, third, fourth, fifth and sixth choices, respectively. So, nanoactuator element (motor stage) alternative M_6 is selected as most appropriate alternative for the considered application and for the design of nanoactuators, if it satisfies the other criteria.

VII. CONCLUSION

The paper presents nanoactuator elements selection procedure based on multiple attributes decision making (MADM) approach, which is a concept used not so frequently for the purpose for optimum selection of nanoactuator elements. It identifies the various attributes needing to be considered for the optimum evaluation and selection of nanoactuator elements. The methodology in broad sense is capable of considering all the life cycle issues starting from conceptual stage of design, production processes, etc. till the disposal or recyclability of nanodevices. Technique for order preferences by similarity to ideal solution (TOPSIS) is more appropriate for optimum selection of nanoactuator elements to design and develop nanoactuators as most of the design, production process, and material attributes, are specified/known.The methodology helps to select an optimum nanoactuator, commercially-off-the-shelf (COTS) from the global market based on attributes corresponding to desired x-abilities in less cost and less time. It provides a coding systemfor nanoactuator elements depicting the various attributes. It recognizes the need for, and processes the information about, relative importance of attributes for a given application without which inter-attribute comparison is not possible. It presents the result of the information processing in terms of a merit value, which is used to rank the nanoactuator elements in the order of their suitability for the given application MATLAB is used to illustrate implementation of proposed methodology with the help of an illustrative example TOPSIS method ensures that the selected optimum nanoactuator elements is closest to positive benchmark (best) solution and farthest from negative benchmark (worst) solution. The methodology is being extended to address the R & D issues related to production processes like: - a) Identification of all the processes in nanoproducts development cycle e.g. conceptual design, detailed design, production planning and control, etc. b) Modelling and designing for manufacture and assembly of nanoproducts including all production processes, etc. c) Optimum selection of nanomaterials design for environment ability. d) Integration of different subsystems into complete nanotechnology system to develop high performance and competitive nanoproducts at low cost for different applications.

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