Conceptual Design of Hammer Handle Shock Absorbance Measuring Machine

Hrayr Darbinyan

Abstract Shock absorbance quality of a hammer handle is an important feature of convenient hammering action avoiding early fatigue because of permanent shock effect in the user's palm. Despite of large variety of hammers available on the market and immense industrial base for producing those products, still there is no quantified standard to limit, describe and compare shock absorbance quality of different hammers. Two different conceptual solutions are considered to deal with this problem. The whole process of conceptual design (CD) is documented in special formats called design pages and including basic steps of conceptual design: composition, decomposition, modeling, synthesis, visualization and evaluation. A comparative analysis of different methods of conceptual design shows the effectiveness of the applied method in terms of direct dependence between mechanism and function, combined with consideration of links used for building a novel structure and function subject for satisfaction and possibility of extension of concept design procedure for modification and usage of known solutions from database, and so on. Comparative charts for shock absorbance quality of a series of well-known brand hammers and for key features of shock absorbance machines per different design scenarios are presented. The actuality of the presented study is determined by setting conditions and managing conceptual design process for large variety of mechanical devices. A specific cross diagonal matrix is developed to describe the features and work tools of suggested CD process.

Keywords Concept · Design · Evaluation · Design · Cycle · Modification

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1 Introduction

As believed by many experts, mechanical design creation of conceptual solution of a novel product is still considered as the most challenging and less explored and understood phase of the whole mechanical design process.

After the boom of machinery and mechanism development initiated by industrial revolution in nineteenth century up to the start of pre-digital era in last quarter of twentieth century, huge knowledge and resource was mostly directed to canonization of terms and tactics of mechanical science and to development of means of parametrical synthesis and optimization leaving a gap for conceptual or structural design.

Growth of accumulated knowledge on mechanical science on one side and dawn of digital area on the other have forced to pay more, defined by necessary attention on the segment of conceptual design. The fundamental approach by Freudenstein [1] is considered to be a pivotal point for this problem, guiding many researchers to deal with the development of methodical background for conceptual design. For example, solid contribution in general methods of conceptual design can be found in studies [2–4]. Development and application of graph-based mathematical tools for conceptual design are widely described in [5], and the authors of [6] invested considerably in development of networks of large mechanical and social systems.

Freudenstein [1] method is based on idea of separation of function and mechanism and leads to creation of specific objects—graphs containing limited functional meaning and distanced away from physical essence of mechanisms in a way that those graph objects are convenient for computational purposes which result in search and choice of novel and acceptable solutions among large variety of considered sets. Actually these two circumstances—limited functional meaning and necessity of consideration of large quantity of options—are limiting the efficiency of application of this method, at least for the class of hand tools, custom-made wood, and stone working machines, and for other mechanisms the author of this paper had successfully completed conceptual design along several decades.

With the start of digital era the efforts directed on search and development of CD methods become more dynamic, explained by coming forward of digital methods as well as with the necessity of shortening of design lead-time and assuring the results that best matches with the growing demand of nowadays market in various mechanical products, including the ones of everyday usage.

Studies [7, 8] are built mainly on this approach. Interesting methodical and computational developments of those studies are directed in finding the solution for main design objective only. Those methods are lacking in consideration of such powerful design tool like construction and usage of models, understanding under this term consideration of a category with limited number of mechanical means responsible for several functional attributes demands. Models are essentially necessary for making a decision at any stage of CD or for the whole CD process. They are assuring such steps of CD process like specification, decomposition, and localization of design task.

A decade-long experience in developing conceptual solutions of mechanical products allows the author for such organization of CD first reported in [9], and that being based on this experience it is best matching with such demands like effective environment of making a solution, building and usage of mechanical functional models and so on. This result becomes possible because of principle of modification and grouping of mechanical and functional sets as per design task.

Such approach satisfies two conflicting demands of design process—growth of modified and formable mechanical-functional fields, defined by creation of environment for new solution on one side, and limiting scale of search for keeping the gradient and target-oriented efficiency of a new solution by squeezing of functional-mechanical (FM) field and constructing proper synthesis models on the other side.

A proper tool set is developed for managing and implementing modification of functional-mechanical set. Some procedures are becoming technically possible as a result of application of well-known descriptive and abstraction means, while other modification tools were developed independently for serving the specific needs of current CD method and specific features like description, growth, and so on. Unified character of tool set and its comprehensive nature should be mentioned among other effective features of proposed CD method.

Recent publications refer to attempts of developing theoretical base for computation of such tools of CD process as growth and squeezing of FM fields, to computerizing of solution search process, and so on. Current paper relates to further abstraction of general CD tools on one side and emphasizes on techniques of numerical evaluation of conceptual solution on the other. Worthy to note that the techniques of solution evaluation organically result from general ideology of CD, thus confirming another proof of unified and comprehensive nature of proposed CD method.

The rest of this paper is arranged as follows: firstly, the basic features of proposed concept design process are introduced by means of sets block of CD components and relations between them, then a newly developed compact presentation format—a cross diagonal matrix is introduced, showing its resource of description of basic steps of proposed CD method and development of a numerical evaluation method. Further on the proposed method is applied two design scenarios of development of hammer shock absorbance machines, revealing this process in so-called design cycle formats, and finally, a numerical evaluation of value of both design scenarios is carried out, showing different outcomes of conceptual design of two hammer shock absorbance measuring machines in comparative evaluation charts.

2 Basic Steps and Components of Proposed CD Method

2.1 Set of Major Components

Set of major components of proposed CD process is shown in Fig. 1. The CD process includes creation phase and evaluation phase after each creation phase or creation cycle. The creation cycle itself can be doubly blocked—into preparation block and solution block and into rough solution block and final solution block. Passages between the blocks are subject of implementation by a standard set of modification tools applicable for different cases. The solution block has two resources: provide a function by a structural chain from database or provide a function by originating a movement. Set of actions presented on Fig. 1 shows the contents of main actions of the proposed CD method subject to the implementation at different stages along progress of CD process. The set of actions includes key steps such as preparation of solution, modification of both functional and mechanical fields, composition of preliminary solution, combined presentation of design task in a single mechanical and functional matrix, and getting the final solution by means of aggregation action.

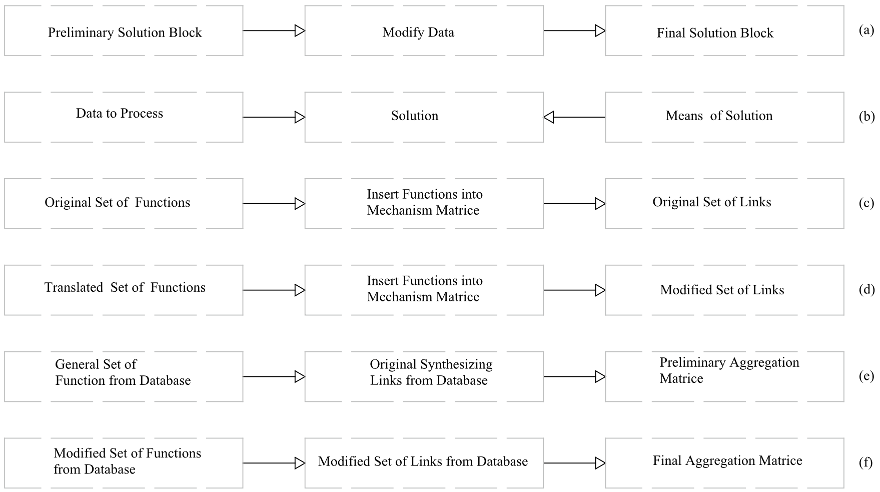


Fig. 1 Set of components and actions of proposed CD method

2.2 Key Models of Conceptual Design

As stated in previous publications, the main idea of the proposed CD process is compactly described in a 2 × 2 matrix where the main diagonal is for components of mechanical system and other diagonal includes upper right part for connections between the links and lower left part for functions task of CD design, for implementation of which the mechanical means and relations are arranged between them.

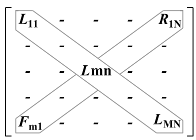
$$M = \begin{bmatrix} L_1 & R_{12} \\ F_{21} & L_2 \end{bmatrix} \tag{1}$$

$$F = \begin{bmatrix} F_1 & T_{12} \\ L_{21} & F_2 \end{bmatrix} \tag{2}$$

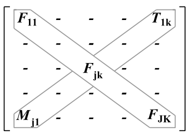
Two key models (1, 2) are constructed in the same manner including links L_1 and L_2 in mechanical model (1) and functions F_1 and F_2 in functional model (2). Links are related by means of mechanical or other relation R_{12} and motivated for such relation by function F_{21}. While functions are related by translation operator T_{12} and such breakdown of functions is making implementation of child function F_2 possible by set of mechanical means L_{21}.

2.3 Cross-Diagonal Matrix

The key models can be generalized into cross-diagonal matrices for compact presentation of modification tools and relations between the blocks of proposed CD method. Links L_{MN} of the mechanical system are arranged on the main diagonal (3) while main diagonal of functional matrix (4) is used for arrangement of components of function set (4). Once rotated on 90° (4) the functional diagonal (6) will coincide with lower left segment of second diagonal of mechanical matrix, thus allowing insertion of segment of functional data into mechanical matrix (7). This shows the combined character of mechanical and functional environment for setting the task of CD and searching solutions for them.



(3)



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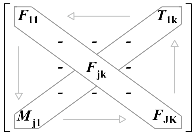

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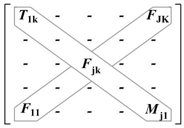

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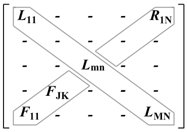


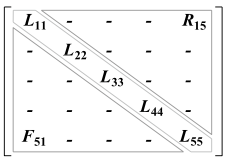
(7)

The matrices (3) and (4) are thus interconnected that emphasizes an advantageous feature of proposed CD method, which is simultaneous consideration of mechanical components and functional data.

In paragraph below cross-diagonal matrix will be used for several steps of conceptual design process, namely for data modification and application, including data expansion, grouping or modeling, and aggregation for getting a novel conceptual solution.

2.4 Data Modification and Application

The term modification in the proposed CD method has wider methodical interpretation, used for modification of both mechanical and functional fields. Modification of mechanical set allows to expand or squeeze the set by adding, subtracting, or combining links. Another case of modification is adding a number of links already used in other mechanism or in database in an attempt to use the demanded properties of this set of links. Cross-diagonal matrix modification means extension or shortening of the length of main diagonal of mechanical matrix (8). The case of functional matrix modification carries the meaning of a function translation for finding a proper sub-function suitable for implementation of mechanical matrix by proper modification.



(8)

$$\begin{bmatrix} L_{11} & R_{12} & - & - & R_{15} \\ F_{21} & L_{22} & - & - & - \\ - & - & L_{33} & - & R_{35} \\ - & - & - & L_{44} & - \\ F_{51} & - & F_{53} & - & L_{55} \end{bmatrix} \quad (9)$$

$$\begin{bmatrix} L_{11} & - & C_{13} & - \\ - & L_{22} & - & C_{24} \\ F_{31} & - & L_{33} & - \\ - & F_{42} & - & L_{44} \end{bmatrix} \quad (10)$$

Both mechanical and functional matrices are subject to modification for three reasons: first, expansion of both matrices for enlarging the field of possible solution and facilitating this search; second, ensuring more general view on the whole CD process or on its single design cycle; and third, creating design environment for focusing on an isolated design problem by grouping several limited number of mechanical means and functions. Another methodical resource hidden in matrix expansion is application in several fields with limited number of synthesis tools, which should be applied for function satisfaction. Technically, matrix expansion has simple interpretation in terms of extending length of main diagonals of both matrices. Taking into consideration similarity and common theoretical base for structuring the both matrices could be a matter of methodical interest, to show connectivity of the matrices in following way.

Grouping or Modeling. The action of modeling and grouping is shown in (9) where links in lower right segment of diagonal are moved into the segment in upper left segment of the main mechanical matrix, diagonally limiting the number of links and contribution in the creation of a model. Similar movements also happen with the functional and relation categories. As illustrated in (9) generalized relation is positioned at R_{15} and then moved to R_{12}, while generalized function is positioned at F_{52} and then moved to F_{21}.

Aggregation or Getting a Solution. As shown in (10) links L_{11} and L_{22} are planned to be connected with solution from database or from self-initiated movement implemented by solution links L_{33} and L_{44}. Planned F_{31} and implemented F_{43} are identical. Aggregation happens when links L_{11}, L_{33} on one side and links L_{22}, L_{44} on the other are connected by unifying symbols C_{13} and C_{24}. Aggregation matrix (10) contains two consecutive subchains: first for preparation of solution with contacting or interface or delegating links ready for connection with analogous links from second solution subchain. Once two chains are constructed aggregation of appropriate links may happen resulting in creation of substructure with beforehand given functions.

2.5 Conceptual Design Evaluation

Conceptual design evaluation techniques [10] are based on breakdown of general function into subfunctions, each having a weighed input into overall value of a mechanical device and can be modified in a way (11) to serve the needs of proposed conceptual design method. They provide values of implemented functions at every step of conceptual design and as well as in the end. Such numerical evaluation implies breakdown of a unit (1.00) into subvalues and provides summarized numerical values necessary for side-to-side comparison of conceptual design cycles with different design scenario.

$$V = \sum_{1 \le n \le N}^{1 \le m \le M} \left[W_n^m Q_n^m + W_n^m (W_{n,n+1}^{m,m+1} Q_{n,n+1}^{m,m+1}) + \cdots + W_{N-1}^{M-1} (W_{n,n+1,\ldots,N}^{m,m+1,\ldots,M} Q_{n,n+1,\ldots,N}^{m,m+1,\ldots,M}) \right] \tag{11}$$

where W_n^m is weight for function F_n and n is the number of functions in a fixed level of functional hierarchy. M indicates the lowest class of tiers in functional hierarchy. m should be considered as index for class of tier in functional hierarchy and not as power.

Q_n^m is a function implementation indicator which turns to $Q_n^m = 1$ when function is implemented and turns to $Q_n^m = 0$ otherwise.

When implementation of a function is impossible and $Q_n^m = 0$, the function F_n is subdivided into subfunctions in an attempt to get an implementable child function. Expression (11) is arranged in a way to allow consideration of tiers in a range of $1 \le m \le M$ and number of subfunctions for each function within the range of $1 \le n \le N$.

At any step of CD process, when comparative evaluation is needed proper indexing techniques should be carried out to allow rearrangement of functions in accordance to their parental or child relationship, and thus allow application solution value calculation and numerical evaluation based on weighted coefficients.

3 Conceptual Design of Hammer Shock Absorbance Test Machine

3.1 Design Cycles of Hammer Shock Absorbance Test Machine

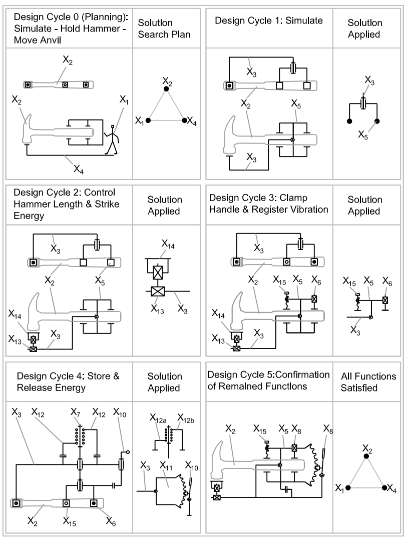
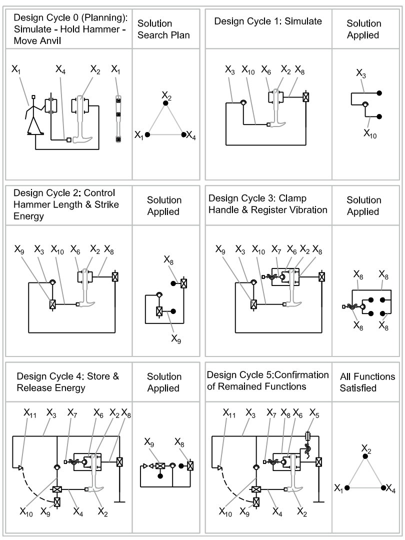
The example of conceptual design used in this paper relates to the development of techniques for quantitative evaluating and comparison of shock absorbance features of handles of different hammers. Choice of various parameters of hammer handle like shape, design, material and material combination follows a single aim to provide the best shock absorbance feature of a hammer handle damping energy flow from head of hammer to the user's palm, thus ensuring comfortable and fatigueless usage of the tool. The idea of developing of a new machine, which is able to measure and register vibration-related data, originated because of absence of such techniques available for multiple hammer manufacturers and hence aims to replace the intuitive and subjective judgment about shock absorbance feature by a strict measurement and quantitative evaluation. Leaving aside the question about mathematical and software processing of vibration signal from its recording to calculation of specific numerical values, which describe shock absorbance feature of a hammer, the test machine had the task of satisfaction of a set of functions necessary to make a qualified device for numerical evaluation of shock absorbance feature.

Some of those functions are: simulation of hammer usage process, control of energy flow from hammer head to hammer handle, registration of vibration signal, storage and release of strike energy, adjustment of hammer handle length and hammer head length, and so on.

Two sets of design cycles are disclosed (Table 1) for development of two different shock absorbance machines developed in 2012 and 2016, respectively. Following the theoretical provisions described above, each design cycle shows solution means or movements used to originate a function and also shows the model used for satisfaction of a solution.

Those two design scenarios are compared from standpoint of implementation of set of required functions leaving apart evaluation of implementation means. For this specific case of two design scenarios, it is obvious that solution per second

Table 1 Design cycles of two design scenarios

<table>
<tr><th>First design scenario 2012</th><th>Second design scenario 2016</th></tr>
<tr><td>
</td><td>
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design scenario uses less mechanical implementation resources than solution per first design scenario. Currently numerical comparison of design solutions is based on evaluation of set of positive or demanded functions only. Anyhow development of a similar numerical evaluation technique, including evaluation of both positive, demanded values and negative values, derived from the progress of conceptual design or necessarily originated by demand of conceptual design is still open and is a matter of further study. In the current study consideration of negative functions is ignored for the sake of simplicity of presenting the evaluation techniques based exclusively on demanded and positive functions, where the advantage of some solution is judged according to higher value coefficient summed as a result of a set of positive functions at different hierarchical levels.

List of Links (2012) used in Table 1: Second Design Scenario

X_1:User, X_2:Hammer, X_3:Ground Link, X_4:Anvil, X_5:Screw, X_6:Boat, X_7:Clamp Screw, X_8:Hammer Handle Length Adjustment Slider, X_9:Pendulum Length Adjustment Slider, X_{10}:Pendulum, X_{11}:Stopper

List of Links (2016) used in Table 1: First Design Scenario

X_1:User, X_2:Hammer, X_3:Ground Link, X_4:Anvil, X_5:Boat, X_6:Register Leg, X_7:Strike Shaft, X_8:Hammer Rest, X_9:Stopper, X_{10}:Ratchet Handle, X_{11}:Ratchet Wheel, X_{12}:Torsion Spring, X_{13}:Hammer Handle Length Adjustment Slider, X_{14}:Hammer Head Length Adjustment Slider, X_{15}:Clamp Screw

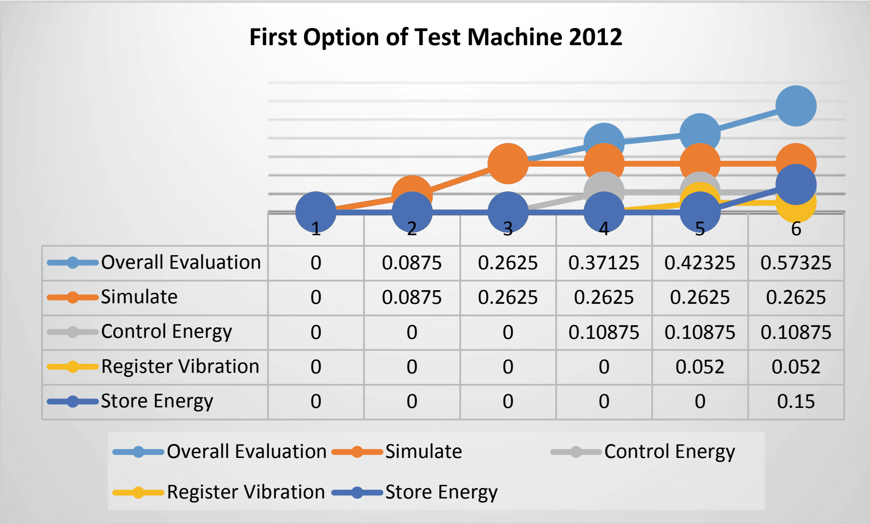
Following two design scenarios, one can state different qualitative results in the end, confirming several advantages of the novel 2016 version. Quantitative evaluation is performed in Sect. 3.2.

3.2 Evaluation Charts of Two Hammer Shock Absorbance Test Machines

A specific calculation program has been developed for computing functional values at five design cycles of two design scenarios for two different shock absorbance test machines. Calculation is based on set of functions available or demanded at each design cycle, weight for value for each function or subfunction, and hierarchical relation between the functions and value of function implementation operator. An example of calculation of a functional value is shown in (12).

$$V = \sum_{1 \le n \le N}^{1 \le m \le M} W_n^m Q_n^m = W_1^1 Q_1^1 + W_2^2 Q_2^2 + W_3^3 Q_3^3 = W_1^1 Q_1^1 + W_2^2 Q_2^2 + W_3^3 (W_{31}^2 Q_{31}^2 + W_{32}^2 Q_{32}^2)$$
$$= 0.2 \times 1 + 0.3 \times 1 + 0.5(0.3 \times 0 + 0.7 \times 1) = 0.85 \quad (12)$$

Five design cycles available in Table 1 were used as argument values in the evaluation charts.



	1	2	3	4	5	6
Overall Evaluation	0	0.0875	0.2625	0.37125	0.42325	0.57325
Simulate	0	0.0875	0.2625	0.2625	0.2625	0.2625
Control Energy	0	0	0	0.10875	0.10875	0.10875
Register Vibration	0	0	0	0	0.052	0.052
Store Energy	0	0	0	0	0	0.15

Fig. 2 Evaluation chart for first design scenario

The same evaluation technique is used for general comparison of functional values of two different machines where numerical evaluation charts are summarized in a final concluding chart showing numerically compared functions at all levels, starting from general evaluation where higher number shows advantage of second option and ending with lowest level functions that drive implementation of all above or paternal functions (Figs. 2 and 3).

As it follows from charts in Figs. 2 and 3, the machine according to second design scenario reaches higher functional values by satisfying more functional demands (better simulation, compact sizes, etc.) and ends in overall functional value equal to one unit (1.00) while the result of first design scenario is reaching to 0.573 only.

4 Conclusion

1. The previously introduced key model of conceptual design is now updated into so-called cross-functional model, thus allowing usage of only one matrix format for compact presentation of both mechanical and functional categories and relations between them.
2. A similar approach is applied for function planning and implementation steps by inserting solutions available in database and from function originating movements.
3. Known [10] function breakdown and evaluation techniques are modified into techniques for concept design evaluation at its every stage and as per overall value. It has been developed as a function of numeration and and indexing method

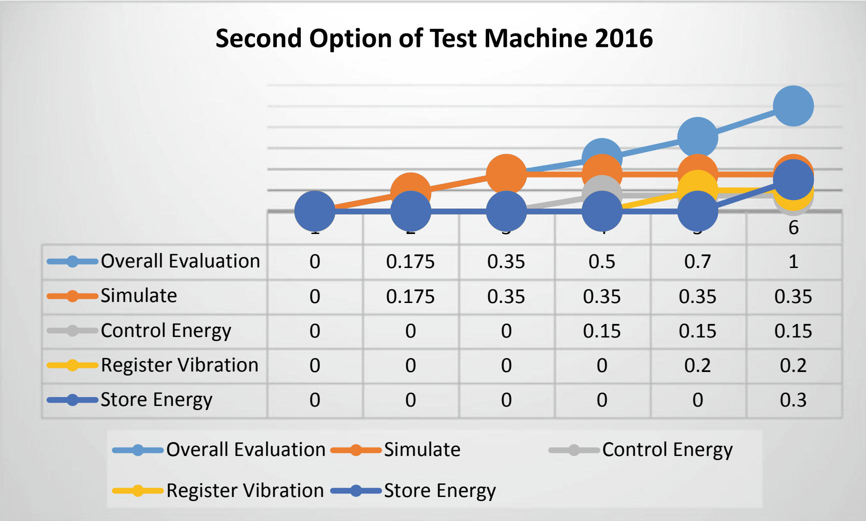


Fig. 3 Evaluation chart for second design scenario

allows satisfaction of expansion, squeezing and grouping features of proposed conceptual design method.

4. The expanded and updated conceptual design methodology is applied for two options of hammer shock absorbance test machines showing the result, status and numerical evaluation of every and each step of concept design and ending with metrics comparison of two conceptual design options in the end.

References

1. Freudenstein F, Maki ER (1979) The creation of mechanisms according to kinematic structure and function. Environ Plann B 6:375–391
2. Yan HS (1992) A methodology for creative mechanism design. Mech Mach Theory 27(3):235–242
3. Tsai LW (2000) Mechanism design: enumeration of kinematic structures according function. CRC Press, New York
4. Dar ZC, Wei MP (2005) A methodology for conceptual design of mechanisms by parsing design specifications. J Mech Des 127(6):1039–1044
5. Xin L, Schmidt LC, Wei DH, Li XL, Yuan MQ (2004) Transformation on EGT grammar: new grammar, new designs. J Mech Des 126(4):753–756
6. Arlitt R, Van Bossuyt DL, Stone RB, Tumer IY (2017) The function-based design for sustainability method. J Mech Des 139/041102-3
7. Chiou SJ, Kota S (1999) Automated conceptual design of mechanisms. Mech Mach Theory 34:467–496
8. Paredis CJJ, Khosla PK (1993) Synthesis methodology for task based reconfiguration of modular manipulator systems. In: Proceedings of 6th international symposium on robotic research. Hidden Valley, PA

9. Darbinyan H (2011) Task based conceptual design method. In: Proceedings of 13th World Congress in Mechanism and Machine Science, A23-559. Guanajuato, Mexico
10. Pahl G, Beitz W (1995) Engineering design, a systematic approach. Springer, NY