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Archiving of structural solutions by task based conceptual design method

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Abstract. The composition of the design libraries and database is essential for finding the optimal structural solution for a task-based conceptual design project. Nowadays the broad usage of digital technologies for the database composition and its update draws on the front line the demand for creating compatible formats for synthesizing and archiving procedures, facilitating the easy and task-based access to the database for the search of the needed solution. It is practical and efficient to organize this process in a task-based manner oriented to a specific group of solutions combined by the field of application and the specific types of tasks. As a result, the general tools of the suggested task-based design method are generalized and updated to the usage of design fragments, which could be general and satisfy for the specific groups of products with their specific properties. The methods and action steps of the named task-based design method are updated accordingly for such a purpose. The method is explained for a large group of locking pliers, showing the general set of properties and the potential design fragments used in the structure of various structural types of these tools.

1 Introduction

The value of any mechanical design is not only in the satisfaction of a design task, development of a product and satisfying the customer needs but also in its ability to accumulate knowledge to ensure recorded input in databases and archives, thus stimulating the further organized usage of the classified data. The procedural success and effectiveness of archiving problems are mostly separated from the development task itself. So far, the developer being responsible for the short-term implementation of the project may care less about database creation and archiving issues, leaving those duty on the side of data recorders or potential users, requiring them not tiny efforts to modify the available data to format subject for further application per designers needs. Considering the circumstance mentioned above from the point of view of a specific conceptual design methodology one can connect the core method of each approach to the development of systemized database, thus evaluating the archiving capabilities of each method. The popular approach of combinatorial search of structural solutions pioneered by and further developed and popularized by [1] emphasize the search of a challenged structural solution among numerously generated topologically abstracted mechanisms independently from functional purposes. Various such topologies compose the appropriate contents of a database which are helpful for the designer for their simplicity and abstract manner; however, they still need the comprehensive functional component necessary for task-based design.

Other design approaches [2,3] specific to the application of task-based block solutions support the formation of task-based block databases. The structural blocks being the units of concept design are subject of application as a whole. They hide the inner procedure of their formation, which is the guideline of a specific, even known mechanism formation and its reinvention upon task-based needs.

Another engine [4] for the search of structural conceptual solutions – the theory of inventive problem solving – provides a flexible though limited synthesizing tool set for possible functions and designers. This approach is still lacking in structural solution results archiving in a systemized task-based manner.

All those methods help implement these tasks just from the point of view of those methods' strengths and conceptual essence and if the primary objective is just one single task and a single topology.

A task-based conceptual design method [5], suggested for more than a decade before, implies the development of brand-new structural solutions based on a task-based manner of structure composition, where the links or structural groups are connected in an attempt to implement some task or group of tasks, and where the result may be developed independently from the existence of a specific mechanism. However, the development path brings to the formation of a brand new or a known solution, thus shortening the time on the search for combinatorial solutions and getting a result satisfying the set of design tasks or suggesting a reasonable tradeoff solution.

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So the advantage of the task-based method or the difference against the methods mentioned above is the task-based nature, which means that any action is done in a task-based manner, the simplicity and unification of the set of design tools, the general concept of the simplification of the design environment (the possibility of shaping the sizes of the design environment upon the user's needs and convenience), according to the objective the designer is going to implement, the variety of the formalization, abstraction and presentation tools. As a confirmation of feasibility, workability, or validation of the technique, it is serving dozens of internationally recognized patents for products developed using the task-based design method.

The strict task-based manner of the suggested conceptual design method implies involvement of needed sets of tasks for every synthesizing action, thus enables to provide consideration of any essential combination tasks and appropriate structures for their implementation, ensuring the capability to fix the core properties of the mechanism in a couple of the structure, responsible for it. Such an approach serves as the base for creating model solutions specific to the product profile and accumulating such data in a database.

Tasks & objectives:

- Formalize the concept design method using graph symbols.
- Update the method by separating a model based fragment of the design scenario, defining the further progress of concept design.
- Show the developed example for structures of three different lock pliers.
- Provide the composition of the fragments.
- Show the creation of various lock pliers using the developed techniques and following the different design scenarios based on the same model.
- Create the model development following the steps and techniques for implementing the task-based design method.

2 Task-based design and archiving problem

2.1 The idea of conceptual design

The idea of the suggested method of conceptual design is in direct dependence (1) of the mechanical structure and the tasks the mechanical structure is intended to perform:

$$A_{mn} = f\,(\,T_{ij}\,) \qquad (1)$$

where: A_{mn} is the contents of the mechanical structure (the mechanism),

T_{ij} is the set of tasks challenged against the mechanical structure.

Double indexing is for components of the both sets is for indication of the component itself ($m= n,\ i = j$) and for indication of a relation between the components ($m\neq n,\ i \neq j$).

2.2 Graph presentation of the idea

A graph G presentation of the mechanical structure shows the contents $G= (V, E)$ contents

A graph presentation of the mechanical structure $G= (V, E)$ contains the set of links V as the vertices of the graph and the set of edges E as connections between them(2).

$$G= (V, E)= (V, E_k, E_t) \qquad (2)$$

The edge E is duplicated by two parallel connected edges of E_t for challenged properties or tasks and by E_k for kinematical links and other types of relations (for examples shape forming movement of a technological tool relative the surface of a workpiece subject to processing). Those two edges are representing the set of tasks the future mechanism should perform. The first edge (E_t) should indicate the design plan (task), and the second edge (E_k) should provide the proper type of connection to implement the given task.

The first edge E_t complies to the conditions (3).

$$E_t = (t_{12}, t_{23},\dots, t_{ij})=A^t{}_{mn} = T_{ij}\ ,\ i\neq j \qquad (3)$$

where $t_{12}, t_{23},\dots, t_{ij}$, are the tasks of the a task set T_{ij} , corresponding to the set of edges of mechanism set $A^t{}_{mn}$.

The second edge E_k edge complies to the conditions (4).

$$E_k = A_{mn} = (a_{12}, a_{23},\dots, a_{mn}),\ m\neq n \qquad (4)$$

where $a_{12}, a_{23},\dots, a_{mn}$, are the links of the mechanical set combined in the mechanism set A_{mn}.

The mechanical set itself consists of links (5)

$$V= A_{mn} = (a_{11}, a_{22},\dots, a_{mn}),\ m= n \qquad (5)$$

where $a_{11}, a_{22},\dots, a_{mn}$ are the links. As mentioned above, a link a_{mn} is double indexed for indication of a link when $m= n$, and for indication of a relationship when $m\neq n$.

Analogously the task set (6) includes the tasks $t_{11}, t_{22}\dots, t_{ij}$ themselves ($i = j$) and the possibility to translate a task into implementable status of a task ($i \neq j$):

$$E_t = T_{ij} = (t_{11}, t_{22}\dots, t_{ij}),\ \ i = j \qquad (6)$$

where $i= j$ corresponds to a specific design task,

$i \neq j$ corresponds to translation operator from a task to an implementable status of a task.

2.3 Conceptual design procedure, the start of conceptual design

Firstly, the two major essential a_{11}, a_{22} links of conceptual design are granted and identified (7).

$$A_{mn} = (a_{11}, a_{22},\dots, a_{mn})=f(Tij)=f(t_{11}) \qquad (7)$$

The purpose of granting the initial two links is to plan an implementation of the initial task t_{11}.

For visualization and topological presentation purposes those links are identified as of vertices of a graph which are connected by two graph edges. The first is symbolizing the mechanical task, those links should perform and the other edge symbolizes the type of mechanical relation $\boldsymbol{a_{12}}$ (kinematic joint in particular) which is responsible for implementation of the above-mentioned task or function.

2.4 Expansion and Squeezing of Both Sets

Further development of mechanical components and task sets is organized and carried out through expansions and further necessary squeezing of the mentioned sets within step-by-step judgments and evaluation of the results. The expansion \ squeezing procedures are formalized by the addition or subtraction of unit links and tasks to the original contents of both sets.

Expansion of a mechanical set means adding a link or a structural group to the existing state of the set in a task-based manner that is challenging to the satisfaction of a task or group of tasks (8).

$$1,1 \le m,\ n \le M +/- S,\ N +/- S \quad (8)$$

where $S=1$ for a single link
$S=s$ for a structural group

Expansion of the task set means translating an initial task into another task subject to implementation and adding new tasks as challenging ones generated due to implementation of the previous tasks (9).

$$1,1 \le i,\ j \le I +/- D,\ J +/- D \quad (9)$$

where $D=1$ for a single task
$D=d$ for a group of tasks

If the link set expansion is enough or satisfies all the current tasks, the new challenging tasks are considered, and the task set is expanded or squeezed analogously. The procedure is continued until all the tasks are satisfied by the updated set of links.

The expanded state of the both sets - formalized by (1) with consideration of set modification procedures (8) and (9) -includes vaster combinatorial possibilities to proceed with the optional structural solution. For organizing this phase of conceptual design specific portions of both sets are limited by the number of components - not more than 5 for each set - isolated and considered separately. Isolation of a subset from both sets is formalized in (10) and (11). Adding single links to the indexes of the units of the mechanical components set creates a maneuvering frontier providing satisfaction of a specific design task.

2.5 Models and local design scenarios

When considering a limited set of mechanical components and design tasks, a practical judgment and evaluation of a task's best synthesis result can be reached. The number of components in mechanical and task sets should be 5 or 6 for easy acceptance and manageability. Those fragments play a significant and crucial role in limiting and visualizing the design task and the mechanical components responsible for those tasks.

$$g[A_{mn}] \subseteq A_{mn} \quad (10)$$

$$g[T_{ij}] \subseteq T_{ij} \quad (11)$$

Subsets formed per (10) and (11) are the models or decisive design fragments playing guiding role for the further conceptual design process. For evaluation of their effectiveness, they are evaluated against satisfaction the specific set of functions (12).

$$Ev[G]= (V, E_k, E_t) = e \quad (12)$$

If $e=1$ the task is implemented,
if $e=0$ the task is not implemented

For getting those limited components subsets the component squeezing actions are implemented against for major sets and mutually dependent two subsets of mechanical components and task components are formed: $g[A_{mn}]$ and $g[T_{ij}]$. When applied for synthesis purposes the procedure is run by addition of links and tasks while in the case of product analyzes the components are combined in decisive subsets leading to the implementation of the core function of the product and development and satisfaction of the further supportive functions per conceptual design needs.

For the products having the same or similar functions that's interesting to anchor to the subset for mechanical and task components which are defining the further product development scenario. Such cross point of design scenario can be considered as the model or substance structure of the product making it similar to other products per implementation of the main task and making it different from the similar products by uniqueness of the further path of structure development.

3 Fragment based analyses of a variety of locking pliers

The backwards order of the procedure described for synthesis actions, that is, revealing the conceptual structure inside the physical prototype or physical description of locking pliers invented for the last 60-plus years, was applied to this group of tools for underlining the crossways of different design scenarios taking essential criteria of adjustment feature of the distance between the jaws for clamping objects of various sizes.

Firstly, the feature of adjustable jaw capacity is searched, classified and separated from the whole set of properties a locking pliers needs to have.

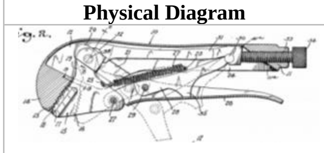
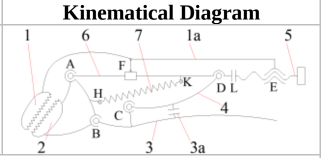
Secondly, the physical diagram of the product is processed to a symbolical state, including the links and kinematical joints.

Thirdly, the kinematical diagram is further processed into graph formats with both kinematical joints indications of the angular and translational movement parameters, adding the edges symbolizing the tasks and properties they perform.

Fourthly, separating and finding the crossways leads to different structural solutions. After confirming the challenged property of adjustable jaws, the rest of the listed properties are provided one by one by the involvement of necessary links and/or structural links for providing single or grouped properties of the locking pliers. Once the whole set of actions of conceptual design is completed, the different structural solutions of locking pliers can be numerically evaluated, as summarized in Tables 1,2,3.

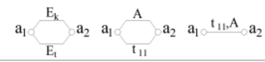
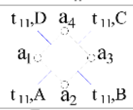
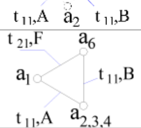
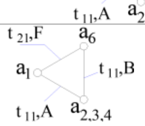
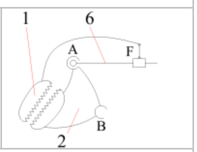
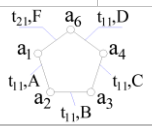
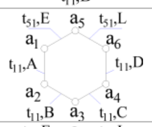
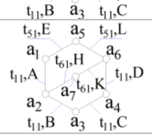
3.1 Design scenario per Pat. 2,768,549

Table 1. Conceptual solution per Pat.2,768,549.

TOGGLE-CONTROLLED PIVOTED JAW WRENCH	
US Patent 2,768,549 - 1956	
A combined plier and wrench comprising a handle having a U -shape in transverse section, a fixed jaw at the forward end of said handle, a movable jaw, said fixed jaw being disposed at an oblique angle relative to the length of said handle, guide means carried by said handle disposed at a right angle relative to the gripping face of said fixed jaw, an elongated jaw adjusting bar disposed in said handle, a pair of slide plates fixed to the forward end of said bar and engaging said guide means, means pivotally securing said slide splats to said movable jaw, means for adjusting the lengthwise position of said bar relative to said handle, a link pivotally connected at one end to the rear portion of said bar, a second handle pivotally secured at its forward end to said movable jaw, means pivotally securing the forward end of said link to an intermediate portion of said second handle whereby in the closed position of said second handle said latter pivot means will be disposed inwardly of the plane between the end axes of said link, to thereby lock said second handle and movable jaw in gripping position, parallel with the gripping face of said fixed jaw, and a spring connected between said first named handle and said movable jaw.	
Physical Diagram	**Kinematical Diagram**
	

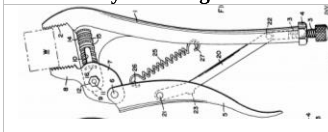
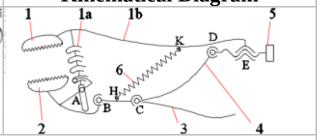
Translated Function Set			
t_1	Perform lock function	t_{11}	Provide high trans. ratio
t_2	Adjustable jaw range	t_{21}	Limited jaw range
t_3	Jaws parallelism	t_{31}	Strictly parallel jaws
t_4	Convenient usage	t_{41}	Natural hand position
t_5	Fixation, adjustable force	t_{51}	Irreversible stop
t_6	Self-operation	t_{61}	Assisted open - close

Translated Link Set					
10	Elongated Handle	a_1	28	Link	a_4
10	Fixed Jaw Member	a_1	33	Adjustment Screw	a_5
15	Clamping Member	a_2	31	Bar	a_6
26	Handle	a_3	27	Coil Spring	a_7

Structural-functional subsets		
1		$A_{mn} = (a_{11}, a_{22}) = f(t_{11})$
2		$A_{mn}=(a_{11}, a_{22}\ a_{33}, a_{44},)=f(t_{11})$
3		$A_{mn}=[a_{11},(a_{22}...a_{44}),a_{66}]=f(t_{11}, t_{21})$
3	 $A_{mn}=[a_{11},(a_{22}...a_{44}),a_{66}]=f(t_{11}, t_{21})$	
4		$A_{mn}=(a_{11},a_{22},a_{33},a_{44},a_{66})=f(t_{11}, t_{21})$
5		$A_{mn}=(a_{11},a_{22},a_{33},a_{44},a_{66},a_{55})=f(t_{11}, t_{51})$
6		$A_{mn}=(a_{11},a_{22},a_{33},a_{44},a_{66},a_{55},a_7)=f(t_{11}, t_{51}, t_{61})$

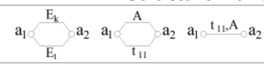
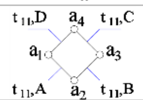
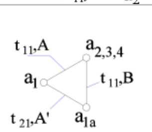
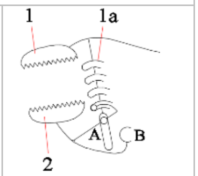
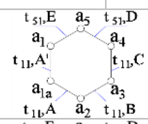
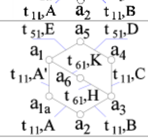
3.2 Design scenario per Pat. 3,672,245

Table 2. Conceptual solution per Pat.3,672,245.

WRENCH	
US Patent 3,672,245 – 1972	
Pliers for positively gripping a selected work piece between substantially parallel gripping jaw surfaces, one of which is carried by a fixed handle, the other of which is carried by a pivoted toggle member mounted on an extension of the fixed handle for pivotal movement and adjustment toward and away from the jaw on the fixed handle, a handle pivotally connected to the toggle member and tensioning means connecting said handles and adjustment means on the fixed handle and having pivotal connection with the pivoted handle whereby the gripping effort on a selected work piece may be adjusted to secure a strong positive grip thereon without causing damage to the work piece.	
Physical Diagram	**Kinematical Diagram**
	

Translated Function Set			
t_1	Perform lock function	t_{11}	Provide high trans. ratio
t_2	Adjustable jaw range	t_{21}	Limited jaw range
t_3	Jaws parallelism	t_{31}	Strictly parallel jaws
t_4	Convenient usage	t_{41}	Natural hand position
t_5	Fixation, adjustable force	t_{51}	Irreversible stop
t_6	Self-operation	t_{61}	Assisted open - close

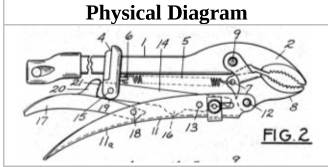
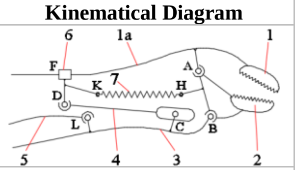
Translated Link Set					
2	Jaw Portion	a_1	5	Channeled Handle	a_3
14	Arcuate Rib	a_{1a}	4	Toggled Arm	a_4
1	Fixed Handle	a_{1b}	3	Adjust. Screw	a_5
8	Jaw	a_2	6	Spring	a_6

Structural-functional subsets		
1		$A_{mn} = (a_{11}, a_{22}) = f(t_{11})$
2		$A_{mn}=(a_{11}, a_{22}\ a_{33}, a_{44},)=f(t_{11})$
3	 $A_{mn}=[a_{11},(a_{22}...a_{44}),a_{1a}]=f(t_{11}, t_{21})$	
4		$A_{mn}=(a_{11},a_{1a},a_{22},a_{33},a_{44},a_{55})=f(t_{11}, t_{51})$
5		$A_{mn}=(a_{11},a_{1a},a_{22},a_{33},a_{44},a_{55},a_{66})=f(t_{11}, t_{51}, t_{61})$

3.3 Design scenario per Pat. 3,545,316

Table 3. Conceptual solution per Pat.3,545,316.

PLIERS
US Patent 3,545,316 - 1970
In a plier type toggle wrench having a handle with a stationary jaw at its front end, a movable jaw pivoted to said front end of the handle, toggle means for forcing the 45 movable jaw toward the stationary jaw including an actuating lever having one end pivoted to the movable jaw and the other end with a hand grip section spaced from and opposite the back end of the handle, an adjustable abutment on

the handle, a toggle link having one end pivoted 50 to the abutment and the other end pivoted to the actuating lever between its ends, the movable jaw being forced toward the stationary jaw by squeezing the hand grip section of the actuating lever toward the handle to bring the common pivot between the actuating lever and the toggle link into dead center relation with the other pivots, a release lever pivoted on the actuating lever for prying me hand grip section of the actuating lever away from, the handle to bring said common pivot to the release side of dead center remote from the handle, said release lever 60 having a catch engaging a cooperating catch element in substantially fixed relation to the handle as the common pivot moves to said release side of dead center to arrest the momentum of the toggle means.		
Physical Diagram		**Kinematical Diagram**
		

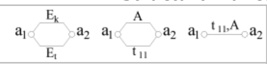
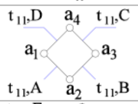
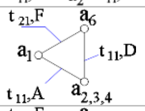
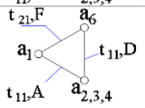
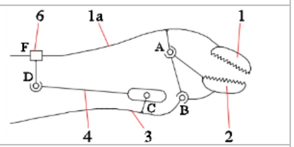
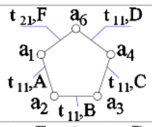
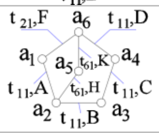
Translated Function Set

t_1	Perform lock function	t_{11}	Provide high trans. ratio
t_2	Adjustable jaw range	t_{21}	Average jaw range
t_3	Jaws parallelism	t_{31}	Strictly parallel jaws
t_4	Convenient usage	t_{41}	Natural hand position
t_5	Fixation, adjustable force	t_{51}	Irreversible stop
t_6	Self-operation	t_{61}	Assisted open - close

Translated Link Set

1	Handle	a_{1a}	14	Link	a_4
2	Fixed Jaw	a_1	20	Catch	a_5
3	Movable Jaw	a_2	4	Tiltable Slide	a_6
11	Actuating Lever	a_3	5	Tension Spring	a_7

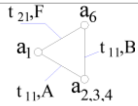
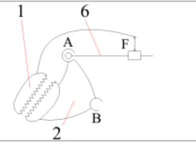
Structural-functional subsets

1		A_{mn} = (a_{11}, a_{22}) = f(t_{11})}
2		A_{mn}=(a_{11}, a_{22} a_{33}, a_{44},)=f(t_{11}
3		A_{mn}=[a_{11},(a_{22}...a_{44}),a_{1a}]=f(t_{11}, t_{21})
3a		
4		A_{mn}=(a_{11},a_{22},a_{33},a_{44},a_{66})=f(t_{11}, t_{21})
5		A_{mn}=(a_{11},a_{22},a_{33},a_{44},a_{66},a_{55}) =f(t_{11}, t_{21} , t_{61})

3.4 Three archived results for the adjustable jaw feature of locking pliers

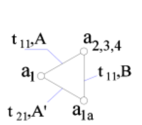
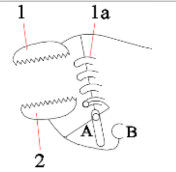
The jaw based on the analyses above the following fragments of design scenarios are pointed out which are defining the further and final features of the synthesized solutions as described below.

Table 4. Design fragment per Patent 2,768,549.

	A_{mn}=[a_{11},(a_{22}...a_{44}),a_{66}] =f(t_{11}, t_{21})	

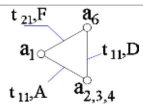
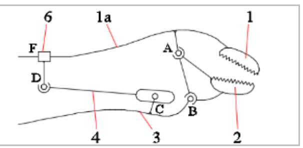
The jaw position adjustability model leads to inconveniency of adjustment action, necessity of two hand application, absence of self-adjustment and self-regulation and strictly to not parallelism of the jaws.

Table 5. Design fragment per Patent 3,672,245.

3		A_{mn}=[a_{11},(a_{22}...a_{44}),a_{1a}]=f(t_{11}, t_{21})	

The jaw position adjustability model leads to a large range of jaw adjustment capacity, the necessity of two hand operation, slower adjustment action, and further tool adjustment for the locking force after the jaw adjustment is made.

Table 6. Design fragment per Patent 3,545,316

3a		

The jaw position adjustability model leads to not parallelism of the jaw flats, slower and not self-adjustment for varying the distance between the jaws, excessive gaps and presence of idler movements in the structure, due to the tiltable sliding member.

4 Conclusions

1. The archiving properties and potential of the conceptual design methods are projected by their core design features and procedural steps.
2. The procedural steps of the suggested task-based design method serve archiving purposes smoothly and allow the isolated design fragments in the entire design process, which are responsible for a chosen main property or feature of the product, as well as tracking the formation of the remaining critical features.
3. The design procedure applies to the examples of locking pliers providing the possible mechanism reinvention path leading to the composition of the final structure and structuring an intermediate solution as a challenged design fragment.
4. As a result, three different design paths for three locking pliers of different years are composed, explaining the essence of the mentioned locking pliers properties.
5. A graph representation of a task-based design problem unifying the contents of both mechanical and task components in a single graph, including the actions for modifying the contents of both sets and the set and types of kinematical joints of the mechanical set.

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