ANALYSING MODIFICATIONS IN THE SYNTHESIS OF MULTIPLE STATE MECHANICAL DEVICES USING CONFIGURATION SPACE AND TOPOLOGY GRAPHS

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ABSTRACT
Automated synthesis of mechanical designs is an important step towards the development of an intelligent CAD system. Research into methods for supporting conceptual design using automated synthesis has attracted much attention in the past decades. In our research, ten experimental studies are conducted to understand how designers synthesize solution concepts for multi-state mechanical devices. The designers vnd that modification of kinematic pairs and mechanisms is the major activity carried out by all the designers. This paper presents an analysis of these synthesis processes, using configuration space and topology graph, to identify and classify the types of modifications that take place. Understanding these modification processes and the context in which they happened is crucial for developing a system for supporting design synthesis of multiple state mechanical devices that is capable of creating a comprehensive variety of solution alternatives.

Keywords: Automated synthesis, multiple state, conceptual design, mechanical device, analysis of synthesis processes, configuration space, topology graph

1 INTRODUCTION

The overall aim of this research is to develop a generic computational system to support designers during the conceptual phase of mechanical design to synthesize a wider variety of design alternatives than currently possible for multiple state mechanical devices. Conceptual design has the most significant influence on the overall product cost [1]. Conceptual design is a difficult task [2], which relies on the designer's intuition and experience to guide the process. A major issue within this task is that often not many potential solutions are explored by the designer during the design process [3, 4]. The major reasons for this are the tendency to delimit a design problem area too narrowly and thus not being able to diversify the possible set of design solutions, possible bias towards a limited set of ideas during the design process, and time constraints [5]. Evidence from earlier research suggests that a thorough exploration of the solution space is more likely to lead to designs of higher quality [6]. Therefore, a support system, automated or interactive, that can help generate a considerable variety of feasible design alternatives than currently possible at the conceptual design phase, is important to the development of intelligent CAD tools that can play a more active role in the mechanical design process, especially in its earlier phases.

Li [5] defined the operating state of a mechanical device by a set of relations between its input and output motions, which remain unchanged within an operating state. A multiple state device has more than one operating state. Other researchers [7, 8] defined state in various other ways. The definition of state used by Li [5] is adopted for use in this research work.

2 RESEARCH OBJECTIVES

The central question to be addressed in this research is – how to synthesize, automatically or interactively, a comprehensive set of possible device concepts that satisfy a given task comprising multiple states? In order to do this, we first wish to understand the process by which engineering designers synthesize multiple state devices. This, we hope, will throw light on how (and how well) multiple state synthesis tasks are currently handled, what can be learnt from these, and how this learning could be used in computational tools to help improve multi-state synthesis tasks. The research work presented in this paper is continuation of our previous work [9], where multi-state design tasks are described in terms of a set of related functions, and this set of functions is given to the designers including the researcher to individually generate as many design alternatives as possible. All the designers are asked to think aloud while carrying out their synthesis processes. These synthesis processes are video recorded. The following practice has been observed in the case of each designer: an initial solution proposal is generated, which satisfies one of the functions of the design task. This initial proposal is modified for satisfying each of the remaining functions, taken one at a time. The initial solution proposal generated and the various types of *modifications*, carried on these solution proposals for satisfying previously unsatisfied functions, led to generation of various solutions. Modifications are found to be the major activity in synthesizing solutions for multi-state design tasks. To understand how these modifications are carried out and in what context, all the synthesis processes are analyzed using configuration space [10] and topology graph [10]. The objective of this paper is to analyze these synthesis processes using configuration space and topology graph in order to understand the modification processes. This understanding should help develop a support which can help generate a wider solution space for a given multistate design task than currently possible.

3 LITERATURE STUDY

Li [5] seems to be the only researcher who has directly addressed multiple state mechanical synthesis tasks. He has used the configuration space approach to represent and retrieve behaviors of kinematic pairs, and developed ADCS system for automatically generating solutions of mechanical devices that satisfy the given multiple state design tasks. However, ADCS is limited to generation of a single solution for a design task, rather than a comprehensive set of alternative designs that are possible to be generated for the task – a critical drawback if the goal is to support generation of a wider variety of concepts. Single state design synthesis [e.g. 11-16] is limited to either synthesizing a single kinematic pair, a mechanism or their combination, for single input and single output tasks using simulation based, configuration space or grammatical approaches. One approach promulgated earlier has been to generate solutions for each single state within a multi-state synthesis task, and find those solutions that are common across all these sets as solutions to the multi-state problem. However, if the intersection of these solution spaces leads to a null space, there would be no solution possible. An alternative approach is to modify, solutions to a single state task of a given multistate design problem until it satisfies all the other states constituting the problem. .

4 REPRESENTATION OF STATES OF MULTIPLE STATE MECHANICAL DEVICES

An existing multiple state device, a door attached with a latch, is a four state device. This device is analyzed for its functioning within each state and its state transitions.

4.1 Multi-state functioning of a door attached with a latch

The functions of a door are to allow and prevent the movement of energy or material. When a door is in the locked state, it completely prevents movement of these to and from the room. When it is in the opened state, it allows movement of these to and from the room. In between these two states, there are opening and closing states as shown in Figure 1. One way in which a door achieves these functions is

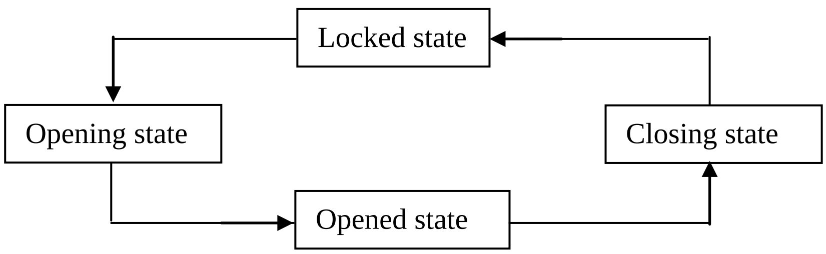


Figure 1. States and state transitions of door attached with a latch

when a latch is attached to it. The functions in each state depend on the type of latch attached to a door. For the type of latch shown in Figure 2(a), the functions performed in each state are:

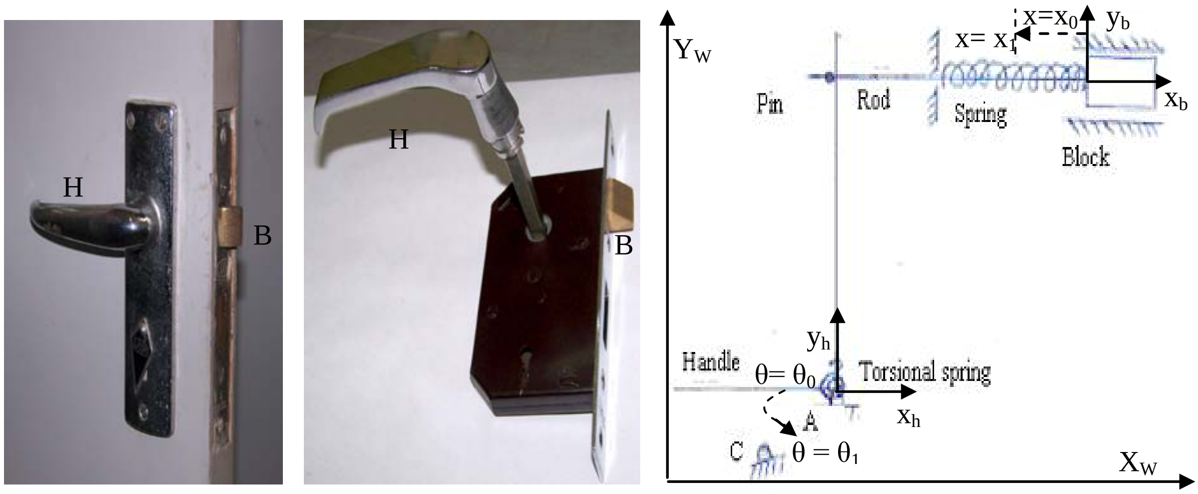
- Locked state: Function1: the door is pushed, but it does not move.
  Function2: the door is pulled, but it does not move.
- Opening state: Function3: the handle is rotated by applying an effort.
  Function4: keeping the effort in the function3 on the handle, another effort is

applied to the door, and the door opens.
Function5: as the effort on the handle is released, the handle rotates back.

- Opened state: Function 6: as the door is pulled, it opens further.
  Function 7: as the door is pushed, it closes further.
- Closing state: Function8: by applying further effort on the door, it comes to the locked state, where further push or pull does not move the door.

The door latch is disassembled to further study its components and interfaces among its components and how this latch when attached to the door attains the functioning of the door. The latch and its components (component H is the handle and component B is the wedge shaped block) are shown in Figures 2(b). From an understanding of these components and interfaces, the overall structure, and the functioning of the latch, the latch is modeled as shown in Figure 2(c). The latch has an L-shaped handle hinged at A, a torsion spring connected to the handle at A, a block, a rod attached to the block and a spring arrangement, where the spring is confined between the block and a support with a hole through which the rod can translate, a small pin attached to the rod protruding perpendicular to the plane of the paper, and a stop at C. This is a plane mechanism. The motion transformations between the handle (component H) and the block (component B) due to various efforts are described below as five functions:

- F1: Apply effort on the handle in anticlockwise direction, handle rotates (from $\theta = \theta_0$ to $\theta = \theta_1$), and simultaneously the block translates inside (from $x=x_0$ to $x=x_1$).
- F2: if effort is kept applied in the same direction when the handle is $\theta = \theta_1$, the handle does not rotate any further due to the obstruction C, and the block remains at $x=x_1$.
- F3: If the effort is released from the handle, the handle rotates back to $\theta = \theta_0$ from $\theta = \theta_1$ and simultaneously the block also translates back to $x=x_0$ from $x=x_1$.
- F4: Now if effort is applied on the block along negative x-axis, the block translates from $x=x_0$ to $x=x_1$, but there is no motion in the handle.
- F5: If the effort on the block is released, the block goes back to $x=x_0$ from $x=x_1$ but the handle does not move.



(a) *(b)* *(c)*

Figure 2. The door latch, its structure and components

4.2 Framing a door latch design task

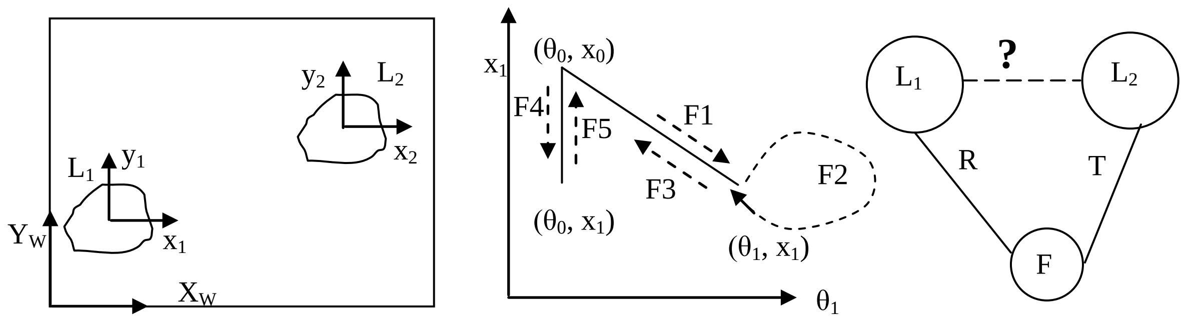
By taking components L_1 and L_2 as shown in Figure 3(a) to act as the handle and the block respectively, a five-function design task can be devised for the above functions as follows:

1. F1: When torque is applied on L_1 in the counter clockwise direction around z-axis, L_1 rotates in counter-clockwise direction around z –axis from $\theta= \theta_0$ to $\theta= \theta_1$, and simultaneously L_2 translates along x-axis in negative direction from $x= x_0$ to $x=x_1$.
2. F2: Even if torque is kept applied in the same direction on L_1, when L_1 is at $\theta= \theta_1$, L_1 does not rotate beyond $\theta= \theta_1$, and L_2 remains at $x= x_1$.
3. F3: If the torque is released on L_1, when L_1 is at $\theta= \theta_1$ then L_1 rotates back in the clockwise

direction from $\theta = \theta_1$ to $\theta = \theta_0$ and L_2 simultaneously translates along x-axis from $x = x_1$ to $x = x_0$.

4. F4: Now if force is applied on L_2 along x-axis in the negative direction, L_2 translates along the axis in the negative direction from $x = x_0$ to $x = x_1$, but L_1 remains at $\theta = \theta_0$;
5. F5: If the force on L_2 is released, L_2 translates back to $x = x_0$ from $x = x_1$, but L_1 remains at $\theta = \theta_0$.

These five functions are given to the designers to generate as many solutions as possible.



(a) (b) (c)

Figure 3. The required configuration space and topology graph for the door latch design task

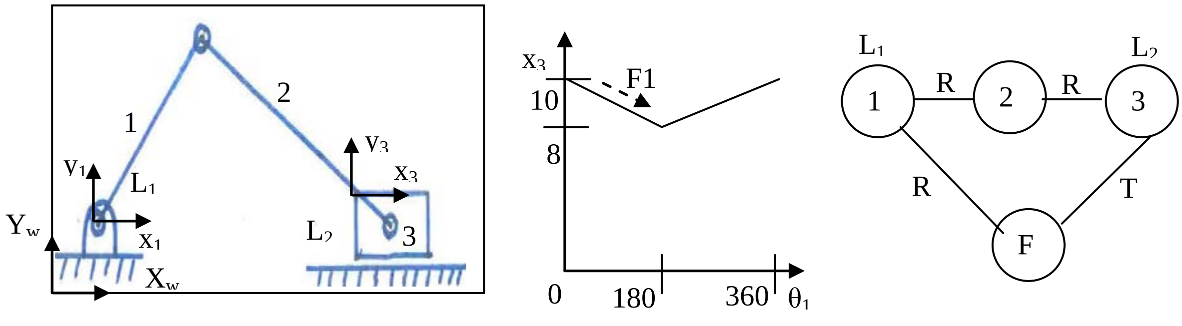
A graph, shown in Figure 3(b), is drawn between the motions of L_1 and L_2. θ is the relative angular motion of the local coordinates system (x_1,y_1) attached to L_1 with the world coordinate system (X_W,Y_W), while x is the relative translatory motion of the local coordinates system (x_2,y_2) attached to L_2 with the world coordinate system (X_W,Y_W). The five functions (F1, F2, F3, F4 and F5) described above are shown in Figure 3(b). F2 involves no change in motions of L_1 and L_2 though effort is applied on L_1. So its starting and end configurations are the same and it is a point on the graph. The topology graph between L_1 and L_2 is shown in Figure 3(c). As L_1 is allowed only to rotate, it forms a revolute joint, R, with the frame (F), while L_2 forms a prismatic joint, T, with the frame. Now the task is to synthesize as many devices as possible, which are sets of components and interfaces, in each set we identify two components which can act as L_1 and L_2 such that they achieve the above five functions.

5 SYNTHESIS OF SOLUTIONS FOR THE LATCH DESIGN TASK

Some of the synthesis processes, carried out by the designers for generating solutions to the door latch design task, are analyzed below using configuration space and topology graph.

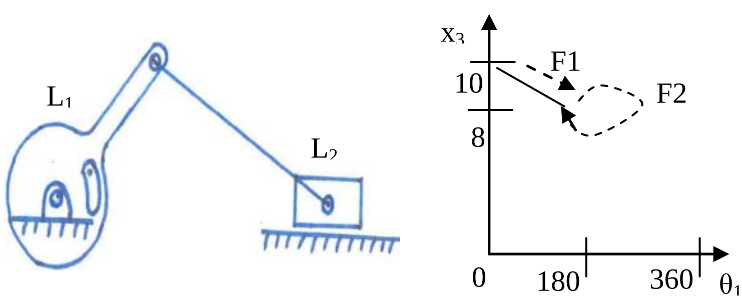
5.1 Solution1

After analyzing the given five functions of the door latch design task, first function F1 is focused on. As F1 requires rotary motion to be converted to translatory motion, a slider crank mechanism



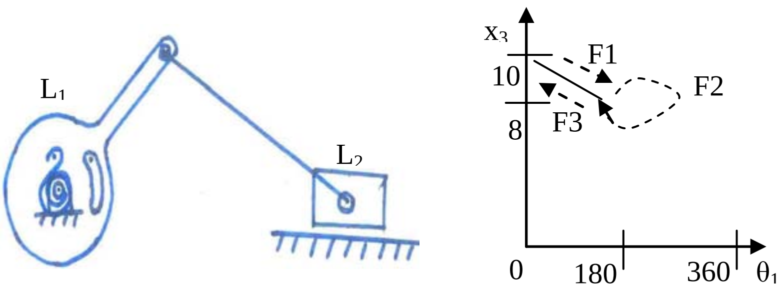
(a) (b) (c)

Figure 4. SP1, its configuration space and topology graph



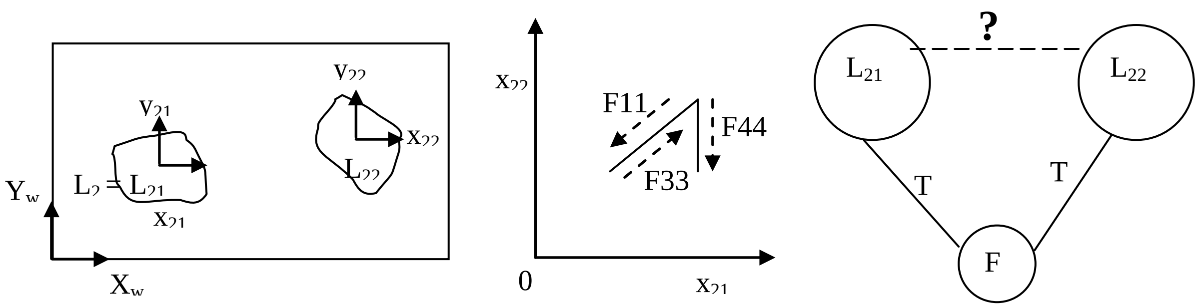
(a) (b) (c)

Figure 5. SP11, its configuration space and topology graph



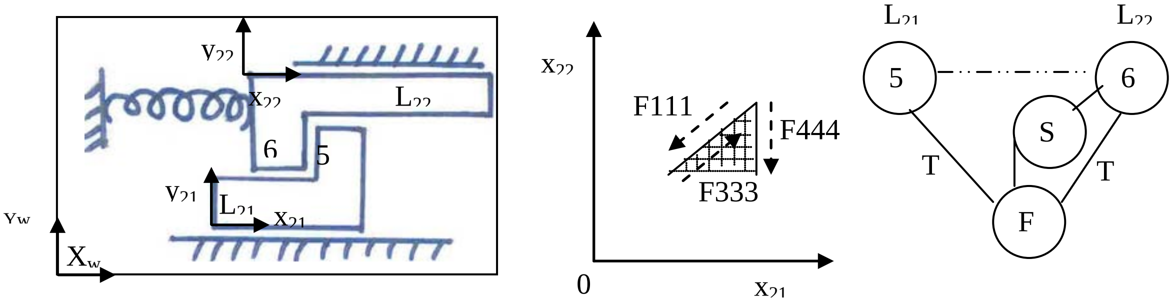
(a) (b) (c)

Figure 6. SP111, its configuration space and topology graph



(a) (b) (c)

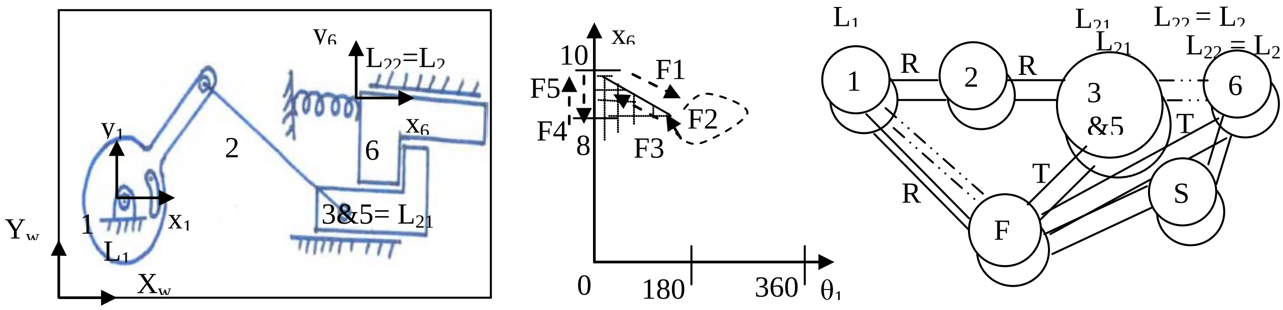
Figure 7. Newly derived design task, required configuration space and topology graph



(a) (b) (c)

Figure 8. SP21, its configuration space and topology graph

is generated. We call this solution proposal1, or SP1. The slider- crank mechanism (SP1), its configuration space and topology graph are shown in Figures 4(a)-(c) respectively. Arbitrary numerical values are assigned for producing the configuration space in Figure 4(b). In the topology graph shown in Figure 4(c), the letters R and T stand for revolute pair and prismatic pair respectively. Here we can identify that the crank (Component1) acts as L_1, and the slider (Component3) as L_2



(a) (b) (c)

Figure 9. Combined solution from SP111 and SP21, its configuration space and topology graph

for function F1. Now SP1 is evaluated against F1, which it is found to satisfy. The same thing can be observed between the configuration spaces in Figures 4(b) and 3(b), i.e. the portion of configuration space of SP1 that is a line between the points (0, 10) and (180,8) in Figure 4(b) matches F1 of Figure 3(b). As F1 is satisfied, F2 is selected next. Keeping F1 and F2 in mind, SP1 is modified with a slot and pin arrangement, shown in Figure 5(a), producing SP11. SP11, its configuration space and topology graph are shown in Figures 5(a)-(c). The change in configuration space can be observed in terms of size reduction based on the slot and pin arrangement. The change in topology graph can be observed in terms of introduction of a line (chained line, which indicates a changing higher pair contact, i.e. the components are in contact at some configurations and not at other configurations.) between Component1 and the frame. As F1 and F2 are satisfied as shown in Figure 5(b), F3 is selected next. SP11 is modified by adding a torsional spring between the Component1 and the frame as shown in Figure 6(a), producing SP111. The configuration space and the topology graph for SP111 are shown in Figure 6(b) and 6(c) respectively. The configuration space remains the same, but the spring addition acts as a motion activator, which is required for F3. The corresponding change in topology graph can be observed by addition of a spring (S_T) between the frame and the Component1. As F1, F2, F3 are satisfied as shown in Figure 6(b), F4 is selected next. In F4, when force is applied on L_2, it translates along the negative x- direction, but without motion in L_1. But when force is applied on the Component3 (i.e. the slider, acting as L_2), Component3 moves and crank also rotates. So F4 is not satisfied, which can also be realized when configuration spaces shown in Figure 3(b) and Figure 6(b) are compared. i.e. the vertical line required in configuration space shown in Figure 3(b) does not exist in the existing configuration space of SP111 shown in Figure 6(b). As F4 is not satisfied, one more component (L_{22}) is chosen to act as the new $L_{2;}$ this L_{22} is to be placed beside the slider (which is considered as L_2 till now; henceforth we call this L_{21}) of SP111. To satisfy F4, L_{21} and L_{22} have to be connected such that when L_{22} is pushed along the negative x- direction by a force, L_{21} should not move inwards. It must be kept in mind that the already satisfied functions F1,F2, and F3 should not be negated with the introduction of the new L_{22}. If the above four functions F1, F2, F3 and F4 are reconsidered with respect to SP111, they can be reframed as follows:

1. F11: if torque is applied on L_1 (the crank of SP111) in counter clockwise direction, then L_1 rotates from $\theta = \theta_0$ to $\theta = \theta_1$, L_{21} (the slider of SP111) translates inside along negative x-axis from $x = x_0$ to $x = x_1$ and L_{22} also has to translate inside along negative x-axis simultaneously.
2. F22: if torque is still kept applied on L_1 (the crank of SP111) in counter clockwise direction when L_1 is at $\theta = \theta_1$, L_1 does not rotate beyond $\theta = \theta_1$, L_{21} remains at $x = x_1$ and L_{22} also does not move.
3. F33: if torque is released from L_1, then L_1 rotates back to $\theta = \theta_0$ from $\theta = \theta_1$, L_{21} translates back along positive x-axis to $x = x_1$ from $x = x_0$ and L_{22} also translates along positive x-axis simultaneously.
4. F44: if force is applied on L_{22} along the negative x- direction, L_{22} translates inwards, L_{21} does not move and L_1 also does not move.

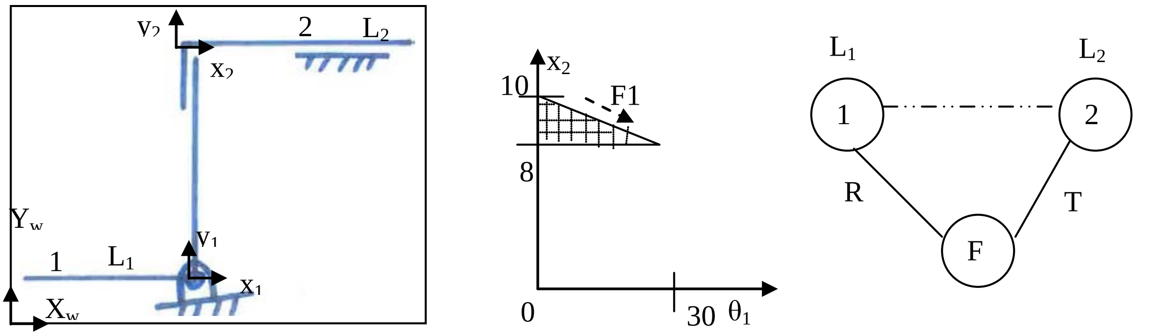
If only L_{21} and L_{22} are considered, the reformulated design task is as follows:

1. F111: If force is applied on L_{21} along the negative x-axis, L_{21} translates inward from $x=x_0$ to $x=x_1$, and L_{22} also translates inside simultaneously.
2. F222: If L_{21} stops, L_{22} also stops.
3. F333: If force is released from L_{21}, L_{21} translates along the positive x-axis from $x=x_0$ to $x=x_1$ and L_{22} also translates along positive x-axis simultaneously
4. F444: If force is applied on L_{22} along the negative x-axis, L_{22} translates along this axis, but L_{21} does not move.

So these functions (F111, F222, F333 and F444) together form a new design task as shown in Figures 7(a)-(c). The solution proposal (SP2) is a pair of two L- shaped blocks as shown in Figure 8(a). Component5 acts as L_{21} and Component6 as L_{22} with a changing contact higher pair interface between them that are constrained only to translate along the x- axis. SP2 is evaluated for F111, F222, F333 and F444. SP2 can not satisfy F333 as there is no motion actuating component. So SP2 is modified by adding a spring(S) between the frame and Component6, producing SP21 as shown in Figure 8(a). The configuration space and the topology graph for SP21 are shown in Figures 8(b) and 8(c) respectively. Now SP111 and SP21 are combined by attaching Component3 of SP111 with Component5 of SP21. The torsional spring between the crank is removed as it is redundant. The combined solution proposal, its configuration space and topology graph are shown in Figures 9(a) -(c) respectively. The combined solution proposal is evaluated for F5. It is found that F5 is satisfied as well as F1, F2, F3 and F4.This can be realized by comparing the configuration spaces shown in Figure 3(b) and Figure 9(b).

5.2. Solution2

A solution proposal (SP1) is generated as shown in Figure 10(a). Its configuration space and topology graph are shown in Figures 10(b) and 10(c) respectively. Component1 and Component2 act as L_1 and L_2 respectively. F1 can be realized as shown in Figure 10(b). As F1 is satisfied, F2 is selected next. SP1 is modified by adding a grounded obstruction, producing SP11 in Figure 11(a). The corresponding changes in the configuration space and the topology graph are shown in Figure 11(b)



(a) (b) (c)

Figure 10. SP1, its configuration space and topology

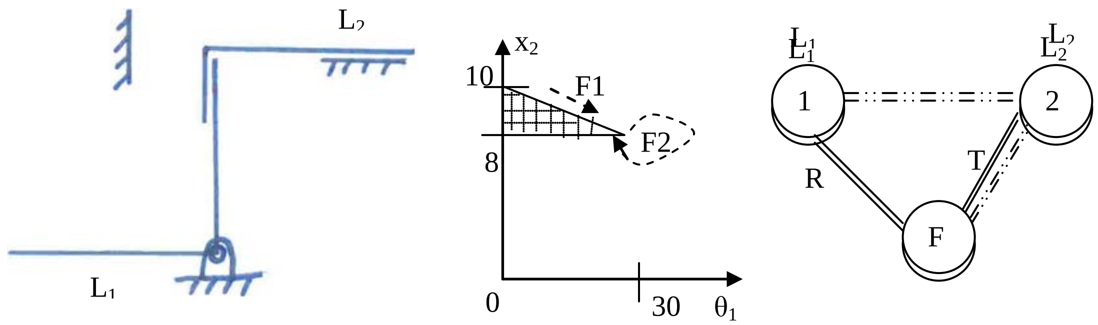


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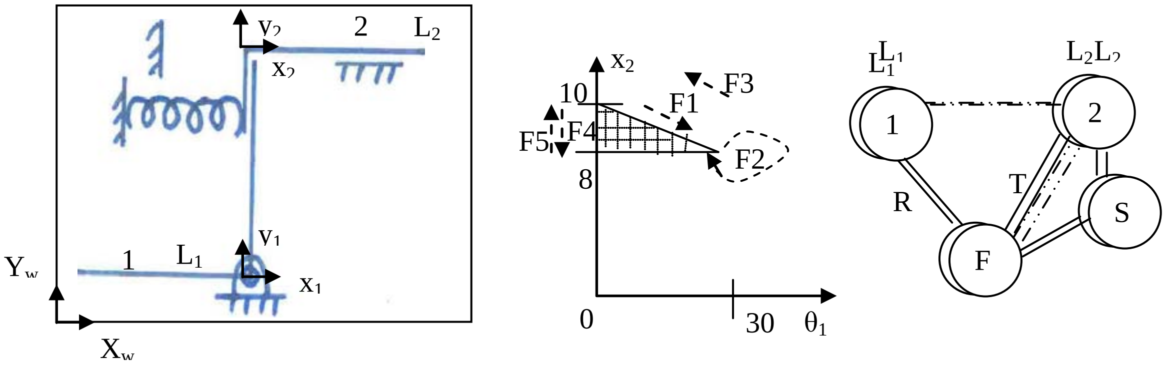
Figure 11. SP11, its configuration space and topology



(a) (b) (c)

Figure 12. SP111, its configuration space and topology graph

and Figure 11(c) respectively. A chained dot line between the frame and Component2 indicates a changing contact higher pair between Component2 and the frame, as shown in Figure 11(c). F3 is selected next. In F3, as effort on L_1 is released, both L_1 and L_2 have to move back simultaneously. So a spring is connected between the frame and L_2, producing SP111 as shown in Figure 12(a). The configuration space and the topology graph for SP111 are shown in Figures 12(b) and 12(c) respectively. As F1, F2 and F3 are all satisfied as realized in Figure 12(c), F4 is selected next. SP111 is evaluated against F4 and is found to be satisfied, as can be observed in Figure 12(b). Next, SP111 is evaluated against F5, and this is also found to be satisfied. SP111 satisfies all five functions, as seen by comparing Figures 3(b) and 12(b). Component1 and Component2 act as L_1 and L_2 respectively.

5.3 Solution3

A gear pair (SP1) shown in Figure 13(a) is selected as the basis for developing a solution. Its configuration space and topology graph are shown in Figures 13(b) and 13(c) respectively. Component1 acts as L_1. Now F1 is selected, and is found that the translating component (L_2) does not

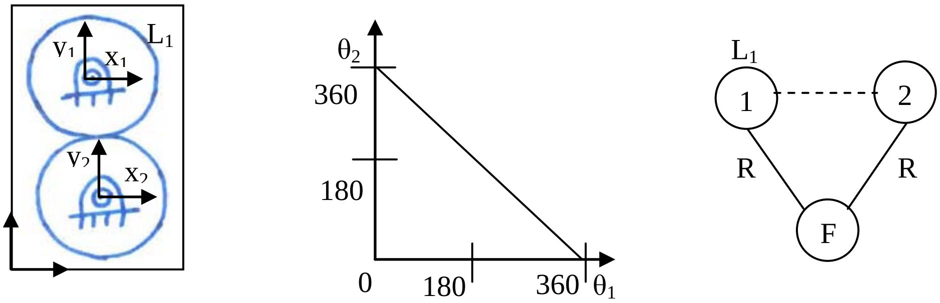


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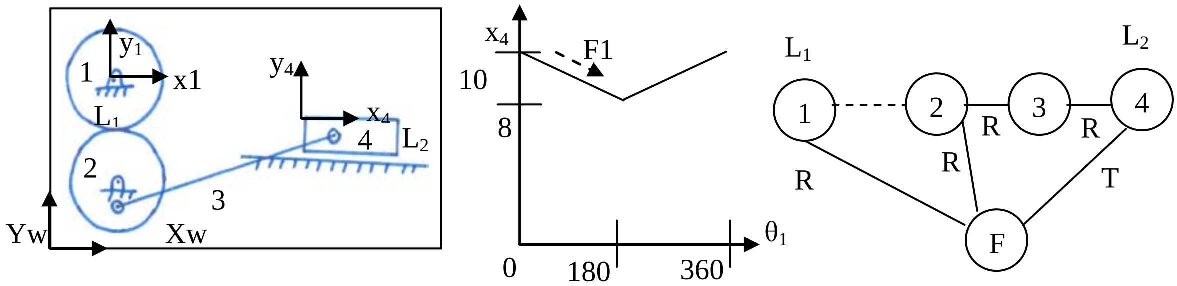
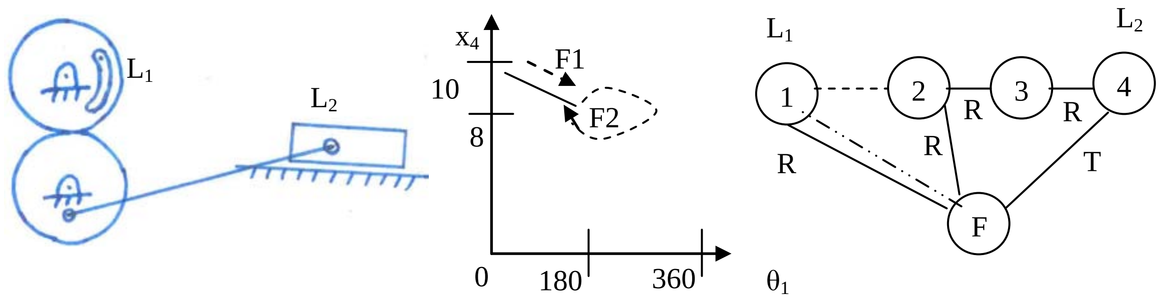
Figure 13. SP1, its configuration space and topology graph



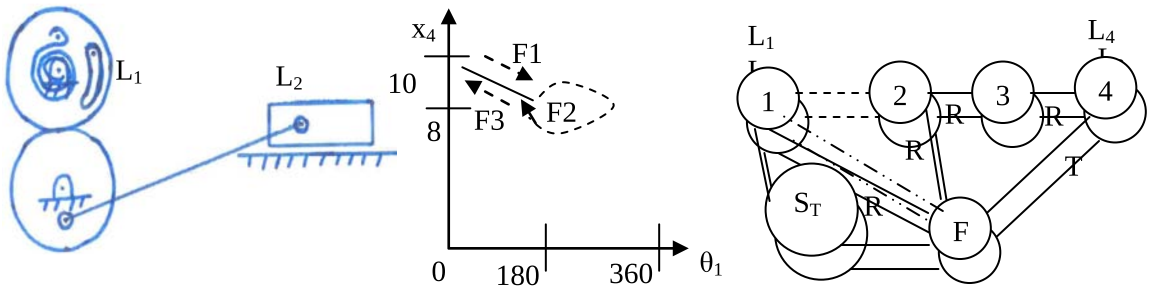
(a) (b) (c)

Figure 14. SP11, its configuration space and topology graph



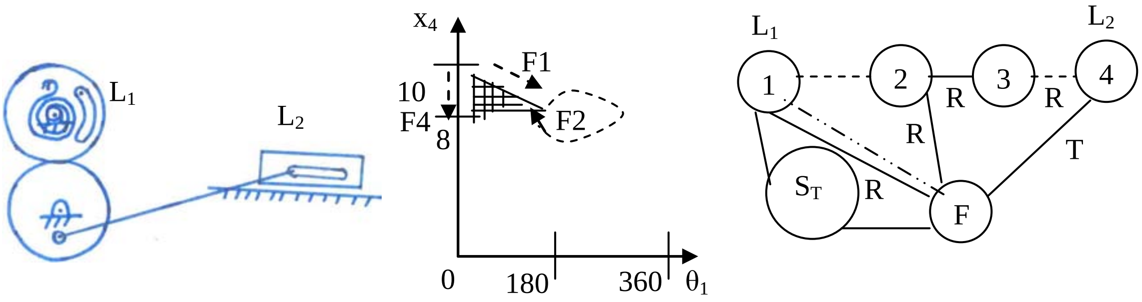
(a) (b) (c)

Figure 15. SP111, its configuration space and topology graph



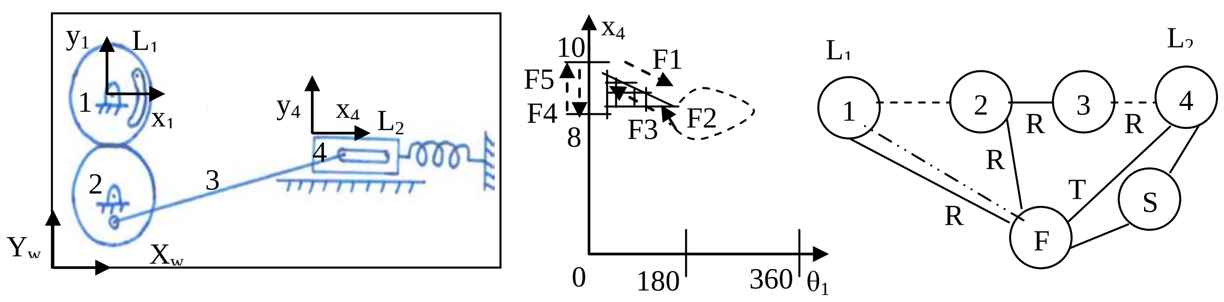
(a) (b) (c)

Figure 16. SP1111, its configuration space and topology graph



(a) (b) (c)

Figure 17. SP11111, its configuration space and topology graph



(a) (b) (c)

Figure 18. SP111111, its configuration space and topology graph

exist in SP1. So SP1 is modified by adding Component4 to act as L_2, which can only translate, and by adding a connecting rod (Component3) between Component2 and Component4 as shown in Figure 14(a), producing SP11. The configuration space (between Component1 and Component4) and the topology graph for SP11 are shown in Figures 14(b) and 14(c) respectively. SP11 is evaluated for F1, which satisfied F1 as seen in Figure 14(b). Next, F2 is selected, and SP11 is modified with a pin and

slot arrangement, producing SP111 as shown in Figure 15(a). The configuration space and the topology graph for SP1111 are shown in Figures 15(b) and 15(c) respectively. Next F3 is selected, SP111 is modified by adding a torsional spring (S_T) between the frame and component1 producing SP1111 shown in Figure 16(a). The configuration space and the topology graph for SP1111 are shown in Figures 16(b) and 16(c) respectively. The realization of F1, F2 and F3 can be seen in Figure 16(b).
Next, F4 is selected. SP1111 fails to satisfy F4, so it is modified by changing the interface between Comoponent3 and Component4 to a higher pair from revolute pair as shown in Figure 17(a) producing SP11111. The configuration space and the topology graph for SP11111 are shown in Figures 17(b) and 17(c) respectively. However, this modification fails F3, as Component4 can not translate back without any effort. So SP11111 is modified by adding a spring (S) between Component4 and the frame and removing the torsional spring (S_T), as it is redundant as shown in Figure 18(a), producing SP111111. The configuration space and the topology graph for SP111111 are shown in Figures 18(b) and 18(c) respectively. If configuration spaces shown in Figure 3(b) and Figure 18(b) are compared, it can be realized that F1,F2,F3,F4, and F5 are all satisfied.

6 FINDINGS AND PROJECTIONS

It is seen that components, their geometries and configurations, and interfaces between them play a crucial role in mechanical functions. It can be observed that in the design sessions studied, kinematic pairs are used as building blocks for constructing mechanical devices. A kinematic pair is retrieved first as it satisfies some of the functions of the multistate design task. It is then modified to satisfy the remaining functions. Let there be a kinematic pair that has two components I and O. 256 (i.e. 2*2*2*2*2*2*2*2) logical combinations can be made between possible existing and required situations of the effort states and motion states of these input and output components of the kinematic pair, as shown in Table 1. On these 256 cases, the following conditions are now applied: the effort state on O is made to be ‘No’ in both the existing and required situations by applying the conditions that efforts are not applied on I and O at the same time and that there is virtual symmetry between I and O (i.e. similar situations would arise by exchanging I and O). So the number of cases of modification possible drops to 64 from 256. By applying another condition that the effort state of I between the existing and required situations remains the same, the number of cases drops further to 32. By applying yet another condition that at least one mismatch between the existing and the required situation must exist for a modification to be applied, the number of cases drops further to 24. These 24 are the distinct, realistic cases of modification that are theoretically possible, and are shown in Table 2.

Table 1. Possible Modification types with Observed Cases

Existing situation				Required situation			
Effort on I	Motion In I	Effort on O	Motion in O	Effort on I	Motion in I	Effort on O	Motion in O
Yes / No	Yes / No	Yes / No	Yes / No	Yes / No	Yes / No	Yes / No	Yes / No

Table 2. Possible Modification types with Observed Cases

	Existing situation				Required situation				Possible Modification
	Effort on I	Motion In I	Effort on O	Motion in O	Effort on I	Motion in I	Effort on O	Motion in O	
1	Yes	Yes	No	Yes	Yes	Yes	No	No	M1
2	Yes	Yes	No	No	Yes	Yes	No	Yes	M2
3	Yes	Yes	No	Yes	Yes	No	No	No	M3
4	Yes	Yes	No	Yes	Yes	No	No	Yes	M3 & M5
5	Yes	Yes	No	No	Yes	No	No	No	M3
6	Yes	Yes	No	No	Yes	No	No	Yes	M3 & M5
7	Yes	No	No	Yes	Yes	Yes	No	No	M4 & M6
8	Yes	No	No	Yes	Yes	Yes	No	Yes	M4
9	Yes	No	No	No	Yes	Yes	No	Yes	M4
10	Yes	No	No	No	Yes	Yes	No	No	M1 & M4

11	Yes	No	No	No	Yes	No	No	Yes	M1,M4 & M5
12	Yes	No	No	Yes	Yes	No	No	No	M6
13	No	Yes	No	Yes	No	No	No	No	M6
14	No	Yes	No	Yes	No	No	No	Yes	M1
15	No	Yes	No	No	No	No	No	Yes	M5 &M6
16	No	Yes	No	No	No	No	No	No	M6
17	No	Yes	No	No	No	Yes	No	Yes	M5
18	No	Yes	No	Yes	No	Yes	No	No	M1
19	No	No	No	Yes	No	Yes	No	Yes	M2
20	No	No	No	Yes	No	Yes	No	No	M5 & M6
21	No	No	No	No	No	Yes	No	Yes	M5
22	No	No	No	No	No	Yes	No	No	M5
23	No	No	No	No	No	No	No	Yes	M5
24	No	No	No	Yes	No	No	No	No	M6

Possible modifications on a pair can be classified into 6 types: M1: Introduce Relative Degree of Freedom (RDOF) between the input and output components; M2: Constrain RDOF between the input and output components; M3: Constrain RDOF between the frame and a component; M4: Provide RDOF between the frame and a component; M5: Introduce a spring between a component and the frame; and M6: Remove a spring between a component and the frame.

To obtain the required situation from the existing situation, at least one of these six modifications need to be performed. For example, in Case1 in Table 2, the existing situation is that when an external effort is applied on the input component, it moves as well as the output component, but the required situation demands that when external effort is applied on the input component, it should move without the output component moving. A possible modification to achieve this is M1, which is to introduce a RDOF between the input and the output components, as observed in the case in Figure 17(a), where a slot and pin arrangement is introduced between the slider and the connecting rod to release the RDOF.

7 CONCLUSIONS AND FUTURE WORK

The behavior and structure of a multi state device can be represented using a configuration space and a topology graph respectively. A series of synthesis processes are analyzed using these, and an exhaustive set of plausible, generic modification processes and their contexts are identified. These processes will be utilized in devising the synthesis rules for developing a multi-state design task synthesis support to help generate a wider solution space for greater novelty and quality.

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