Comprehensive Design Process of Planar Mechanisms for Small and Medium-sized Companies

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Abstract - A process for the design of planar SDOF mechanisms for small and medium-sized companies was developed. The process incorporated tools from several theoretical design processes. The developed design process was tested using a case study, in which a self-closing mechanism for linear slides was designed using the developed process. The case study proved the process to be effective, with the designed mechanism satisfying all requirements.

1 Introduction

In industry, companies use custom design processes specifically tailored toward the companies' products. Normally these processes concentrate on in-company data management and dimensional synthesis more than they do on type synthesis. Also, while theoretical techniques for product redesign exist, they are not normally included in these design processes, thus making the potential redesign process informal and not standardized.

A new comprehensive design process for mechanisms with planar coupler curves for linear motion slides was developed during conducting the senior project in China. It is targeted at small to medium size companies, and incorporates tools from several general as well as specific design processes. The process concentrates on conceptual design, includes elements of redesign based on modified design dependency matrices, and is presented using both general and detailed flowcharts.

The developed design process assumes a generic, non-technical task given to the design team by a customer or a manager. A specific sequence of steps for problem formulation and background research is proposed. After check for redesignability of existing solutions is made, the process splits into either the redesign branch or new design branch. The new design branch guides the designer through type synthesis and part of dimensional synthesis. Type synthesis includes guided choice of coupler plane, type of coupler curve, and type of mechanism to trace it. Design analysis is not discussed in detail, because engineering software is available for mechanism analysis. The developed design process is iterative, therefore it is at any point possible to reverse a previously made decision and go toward a different branch.

The new design process was implemented using a case study. A self-closing mechanism for an existing linear slide mechanism designed by Central Industrial Supply Company was designed using the new process. The process proved to be successful, with the self-closing mechanism satisfying every requirement by 100% or more while the mechanism appeared to be the simplest one.

2 Existing Design Processes

Several design processes for mechanisms already exist and are used in academia and by companies. Part of the reason this project was done is the fact that existing design processes tend to be either very general, providing more of a list of bullet points than a sequence of actions. Another reason is the fact that most current design processes do not contain a specific reference to redesign.

Some design processes used in industry are, on the other hand, highly specialized for the specific companies' needs. These processes tend to be quite complex; therefore, one of the requirements for the process presented in this paper was simplicity.

2.1 Classic design process

This chapter describes the design process suggested by Professor Norton of Worcester Polytechnic Institute[1]. This is a very general design process applicable to both mechanisms and machines; it is therefore applicable but not optimized for small and medium-sized companies. It shares many features with other general design processes, and is given here simply as an example. This process is iterative, in that the progress is normally made by making two steps forward and one (or more) step back, as necessary. It consists of 10 steps, which are:

1) Identification of need.
2) Background research.
3) Goal statement.
4) Performance specifications.
5) Ideation and invention.
6) Analysis.
7) Selection.
8) Detailed design.
9) Prototyping and testing.
10) Production.

2.2 Design Dependency Matrix (DDM)-based rapid redesign

An idea not mentioned in section 2.1 above is that of *rapid redesign*. The approach to rapid redesign of Decomposition Patterns (later in this paper denoted as "*rapid redesign*") – is an approach suggested by Professor Simon Li of University of New Brunswick, CA and Dr. Li Chen of United Technologies Research Center, CT, USA in several papers[2-4].

Rapid redesign uses the notion of a *Design Dependency Matrix* (later in this paper denoted as "DDM"); see the first matrix in Fig. 1 below:

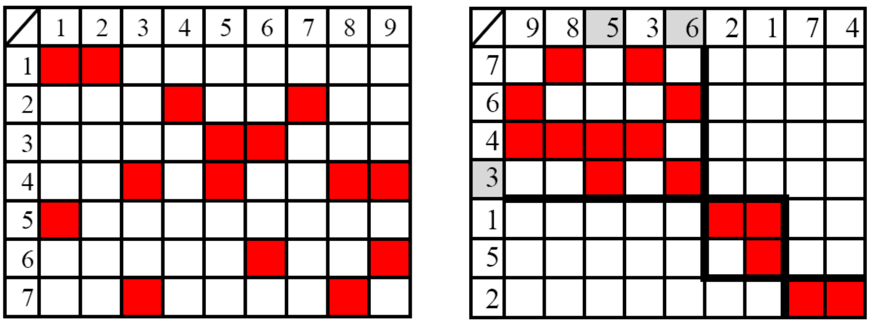

Fig. 1 Sample Unbanded Design Dependency Matrix (DDM) and Banded DDM (adapted from [3])

In a DDM, each column represents a *design parameter*, and each row represents a *performance parameter* (Li[3] calls the rows "*design functions*"). A design parameter is a parameter that describes the structure of a mechanism. Similarly, a performance parameter is a parameter that describes the function of the design and how well the design satisfies the function.

The DDM is a binary matrix – it only contains information about dependency between the mechanism's design and performance parameters, denoted by the different color squares in Fig. 1 above. A shaded element indicates that the design parameter depends on the performance parameter, and a blank element indicates that the two are independent. Use of DDM can be complicated, but for the purposes of this project rapid redesign using DDM can be simplified.

The first step in the general redesign process is defining the design parameters that describe the structure of the mechanism.[3] These can be both qualitative and quantitative, but the key attribute of an appropriate design parameter is that the parameter is independent and not a function of other design parameters. The second step is defining the performance parameters that describe the mechanism's function. These can also be both qualitative and quantitative, but the key attribute of an appropriate performance parameter is that it has to refer to the customer specifications.

The third step is to fill in the DDM, indicating which design parameters are dependent on which performance parameters. Typically, several design parameters affect any given performance parameter. Proper descriptive definitions of design and performance parameters are very important[3].

After the DDM is defined it needs to be *decomposed.*[3] The purpose of decomposition is to turn the DDM into a diagonal, or (more often), banded matrix. The second matrix in Fig. 1 above illustrates a sample banded matrix, which resulted from the decomposition of the sample DDM in Fig. 1 above. The purpose of the decomposition is to divide the problem into autonomous (such as in the banded matrix in Fig. 1 above) or nearly autonomous blocks (Ref. [3]).

The fifth step is to identify which performance parameter or parameters do not satisfy current requirements, meaning the parameters are faulty ([3]). The row or rows that correspond to the faulty performance parameter are highlighted. The column, or columns that correspond to the design parameters, which relate to the faulty performance parameter are highlighted as well (gray shade in the banded DDM in Fig. 1 above).

The sixth step is to fix the performance parameter's native block, in a predefined order using a complicated algorithm; in a non-autonomous matrix the adjoining block may need to be fixed as well.

The purpose of the rapid redesign approach is its use as an organizational tool. It does not identify the nature of changes to be made to the design parameters. Rapid redesign identifies the optimal order of making the changes to the design, thus making the redesign process as efficient as possible.

2.3 New design process details

Based on our research presented above, the process presented below is innovative because:

- It suggests a specific format for background research.
- It implements a formal redesign procedure.
- It introduces the concept of workspace definition.
- It implements linkage transformations in the design process, and not just as an analytic technique.

3 New design process description

The new design process consists of two main branches: redesign and new concept generation. Its primary steps were modeled after Professor Norton's design process (see section 2.1 above). The redesign branch of the design process was adapted from Professor Simon Li's and Dr. Li Chen's articles on decomposition-based rapid redesign (see section 2.2 above) as well as principles of value engineering (outlined in [5]). The new concept branch of the process was designed specifically for planar SDOF mechanisms using transformation rules from Ref. [1], and basic principles of mechanism synthesis and analysis (see section 2.1 above). Separating of functional and structural requirements was adapted from a research paper on parsing design specifications (see section 2.2 above).

Figure 2 below shows the outline of the general stages in the developed design process. The design process consists of several general stages, with the most detailed stage being the Conceptual Design stage. The process is designed to be continuously iterative; however on the accompanying flowchart this is not explicitly stated. At any point in the process the design team can reiterate to any of the previous steps as necessary. Each general stage of the process is outlined below, with the conceptual design and rapid redesign stages given the most detail.

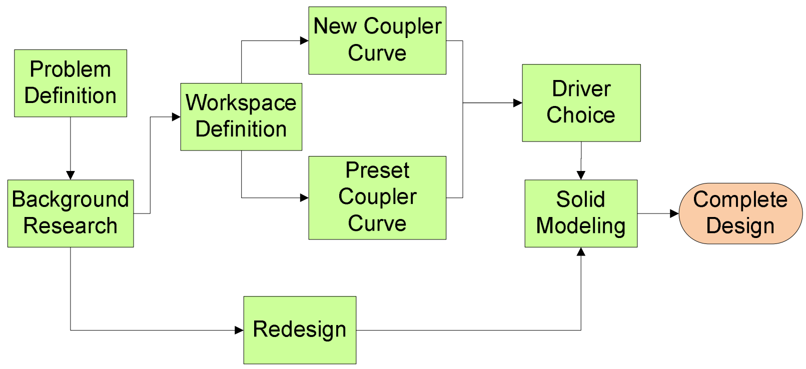

Fig. 2 Developed Design Process Outline

3.1 Identification of problem and goal

In the first stage of the design process, the design team identifies the problem, develops a goal statement and outlines the functional and structural requirements of the design. This starts with communication with the customer (or the design manager). The customer's order is likely to be very broad and specify desired functions for all of the mechanisms in the system (this design process is just for one of them at a time), without stating which mechanism performs which function. From the customer's order the design team has to develop a categorized list of functions. At this stage the design team specifies the mechanism type(s) that perform(s) the functions the customer listed. From the categorized required function list the design team can extract the customer's specifications for the mechanism to be designed.

From the customer's specifications for the mechanism to be designed the design team has to develop a problem statement. A well–structured problem statement will outline the problem the mechanism is supposed to solve using non–restrictive language. Once the problem statement is made, the performance specifications are outlined. The performance specifications include two components: functional requirements and structural requirements. Functional requirements consist of the consumer's specifications and quantitative engineering specifications. Structural requirements consist of how much space the mechanism can occupy, and if it is part of some engineering system – where on that system it can be located. This is determined by the design of the system itself which should be at least partially complete at this point.

After performance specifications are outlined, a goal statement can be generated. The goal statement will, in one sentence, describe the proposed final design. The goal statement, once created, can be used as a quick reference in the decision process at the idea generation step. The creation of the goal statement completes the first major stage of the design process.

3.2 Background research

Locking Mechanism	Type	Type of Locking Element	Type of Obstacle	Length, Thickness, Height (in)
Existing Mechanisms				
Locking Mechanism 1	Front lock	Straight spring slider	Barrier	1.14x0.79x0.08
Locking Mechanism 2	Front lock	Flat spring slider	Barrier	2.48x0.43x0.16
Locking Mechanism 3	Rear lock and staging lock	Torsion spring slider	Pin	1.85x0.79x0.31
Locking Mechanism 4	Rear lock	Rotating element	Trap	1.42x0.79x0.39
Patents				
6764149	Front lock	Flat spring	Trap	
6296338	Front lock	Flat spring	Barrier	
6926377	Front lock	Flat spring	Pin	
3995927	Front lock	Rotation hook	Barrier	
6929339	Front lock	Torsion spring slider	Trap	

Fig. 3 Sample Database for a Locking Mechanism Manufacturing Company (Excerpt from test database for Central Industrial Supply Company[6])

The second major stage of the design process is background research. For a small or medium-sized company which manufactures similar products, a special database format is suggested. An example for a company which manufactures locking mechanisms for linear slides is illustrated in Fig. 3 above; the actual database is many pages long, so in this paper is just an excerpt. An actual database in the same format contains all of the company's designs and patents (both belonging to the company and not) that the design team previously came across when designing similar mechanisms. As such, the database is intended to be a dynamic document, intended to expedite background research process. In case of the locking mechanism company, the engineering specifications, the entire slide's design and relatively well-formulated customer specifications already exist. Therefore, the purpose of background research can be limited to checking for applicable patents and previous designs, and helping the ideation and invention stage. If the customer specs (created in section 3.1 above) are still unclear at this point, inspection of the database for mechanisms which appear to satisfy some of the stated requirements can help the design team formulate the customer specifications precisely. This approach may somewhat limit the creativity but is intended to speed up the design process.

Each column in the database corresponds to a design or a performance parameter of the mechanism; see section 2.2 above for definitions of these terms. The design parameters can be directly controlled by the designer, and may include things like dimensions, or type of spring used. Performance parameters are functions of one or more design parameters, and typically include things like weight, power-to-weight ratio, volume, stability, etc. We also suggest adding less obvious factors that normally would not be thought of as "performance parameters" to this list – part manufacturability, ease of use, and any other parameters that may help judge the quality of the mechanism. Structural requirements typically correspond to certain design parameters, and functional requirements – to performance parameters.

The background research stage is separated into two major steps: inspection of the database for existing designs with similar performance specifications, and inspection of the database for patents with similar performance specifications. This stage is conducted early in the process primarily to saturate the engineer's mind with relevant ideas and let the subconscious generate the ideas by means of subconscious iterations (see Ref. [7] for more information on the subject of mental iteration in mechanical design). Another point of the background research stage is to help (later in the process) test for whether or not any of the designs fully satisfy the performance specifications, or are prone to redesign.

3.3 Conceptual design

The conceptual design stage is the most developed and most important stage in the design process. It includes several choices, so the engineer has to always be aware of the fact that the process is iterative and that if a previously made choice was incorrect the other choice should be investigated.

3.3.1 Previous design and proneness to rapid redesign checks

First the engineer has to check the database for any existing designs that may already satisfy the performance requirements – if there are such designs, then the engineer should use them, and the process is complete. Assuming such a design has not yet been developed, the next choice to be made is whether or not there are any mechanisms in the database (discussed in section 3.2 above) prone to rapid redesign. A recommended indication of this is the following: a mechanism is prone to rapid redesign if only changes to the size of the elements or the type of release mechanism are required to make the locking mechanism satisfy the performance specifications. Any other mechanism is not prone to rapid redesign.

If there is a mechanism is prone to rapid redesign, the decomposition-based rapid redesign methodology (adapted from that described in section 2.2 above) must be applied. It is described in section 3.3.2 below. If there is not a mechanism prone to rapid redesign, a new concept must be developed. The new concept development is described in section 3.3.3 below.

3.3.2 Rapid redesign

The Design Dependency Matrix for the company's mechanisms is required for applying the rapid redesign methodology. If the database has been built, design and performance parameters have been identified, the only thing left is to identify dependence between performance and design parameters; doing so creates the DDM. References [2-4] discuss various banding algorithms. It is only necessary to band the matrix once, because assuming no other performance or design parameters are added, the connection between the design and performance parameters will not change, therefore the DDM will remain the same. The quick redesign algorithm presented here is a simplification of that discussed in section 2.2 above.

The first step in the redesign process is to directly change only the design parameters that influence the faulty performance parameter. If there is more than one faulty performance parameter, new concept design is recommended. The second step is to readjust any of the design parameters that are responsible for the performance parameters that may have been affected by the changes made in the previous step. Ideally, this step will not be required. Some reiteration of these two steps can be applied to bring all of the performance parameters to be acceptable; if this does not happen, new concept design is recommended. It is imperative that the design team does not spend too much effort on redesign, as for relatively simple mechanisms developing a new one is often easier.

After all of the performance parameters have been fixed, the next step in the redesign process is implementation of the value engineering principles[5]. This has been reduced to decreasing cost, by eliminating parts, and / or features, which do not contribute to the function of the mechanism. Upon completion of this step it is possible to move straight to solid modeling and FEA (section 3.3.4 below).

3.3.3 New concept development

If redesign and value engineering principles cannot be applied to generate a mechanism that will satisfy performance specifications, then it is necessary to develop a new concept. Development of a new concept consists of several steps which occur prior to solid modeling. They are described below. Notice that step 3.3.3.1 below is relevant only for mechanisms that are intended to be parts of bigger systems.

3.3.3.1 Workspace definition

The first step in the development of a new concept is checking the functional and structural requirements for orientation. After doing so, the engineer must pick the location of the planar mechanism in the system the mechanism is to be part of.

In a planar mechanism the relative motion between any of the parts and the ground occurs only parallel to some given plane. Therefore, it is easier to first choose the orientation of the plane, and then the location of the mechanism in that plane. To choose the location, the engineer must inspect both normal and tangential planes for potential interferences. The interferences are defined as features on the system that can either run into the mechanism during its operation, or have the mechanism run into them. Based on the check, the engineer must define the workspace. The workspace is a planar drawing, easily drawn on a piece of paper. However, the optimal way to create the workspace is using a conceptual software package, in order to later use it to generate the mechanism. SAM 5.1[8] and Working Model 2D[9] are some examples of such software. The workspace illustrates three types of space: the space which is available to the coupler at all times during the system's operation, the space which is available to the coupler only at some intervals of the system's operation, and the space which is completely unavailable.

3.3.3.2 Mechanism synthesis

At this point the design process splits again. After the workspace is defined, the engineer has to decide whether or not a preset coupler curve for the locking element's motion in the workspace can satisfy the mechanism's functional requirements defined in section 3.1 above. This process identifies two preset coupler curves: a straight line and a circular arc. These coupler curves are treated separately because of their simplicity, specific type of joints they imply, and wide range of tasks they can complete.

If a preset coupler curve is being used, the engineer must first pick whether to use a straight or a circular arc coupler curve. When the curve is picked, the engineer should draw it on the drawing of the workspace, for easy reference. If a circular arc coupler curve is picked, the next step is identifying the location of the pin joint between the coupler element and the ground, and the element's length. If a straight coupler curve is picked, the next step is identifying the location and the length of the prismatic joint between the coupler element and the ground. After this is complete, one can proceed to the choice of energy source – the driver.

If a new coupler curve is being used, the engineer must first define three points on the drawing of the workspace. These points will be used for a pin-jointed linkage synthesis algorithm, and they will be the positions that the coupler point sweeps over its path. The limitations of the workspace (what part of the workspace is available when) restrict where these points can be located. These points must be chosen in such a way that the coupler does its job when it moves from one point to the other – for example, if designing a lock, the points are the positions the locking element (usually a pin) occupies as it moves from the locked to the unlocked state and vice versa. When the three points are defined, a graphical synthesis procedure for fourbar linkage synthesis with fixed pivots[1] can be used to define a coupler curve for the coupler point, and a corresponding fourbar linkage that traces it.

The mechanism to be designed is assumed to have one degree of freedom, so a fourbar or a sixbar pin-jointed linkage are going to be the most common linkages for tracing the coupler curves. The first linkage to try is a fourbar linkage, due to the fact that the precision of the coupler curve tracing is usually not important for the purposes of most simple mechanisms.

After the pin-jointed linkage is defined, the transformation procedure can be applied to it. The point of the transformation procedure is to attempt to convert the mechanism from a pure pin-jointed linkage to a planar linkage with pin, prismatic, roller or half-joints. Planar linkages can be transformed using a set of rules, to retain the same number of degrees of freedom. A linkage transformation transforms the type of the linkage, thus potentially changing the order of joints, the type of joints and the number of links in the linkage, while retaining the number of degrees of freedom. There is no set procedure to follow while transforming a linkage, however, Norton[1] outlines six rules for linkage transformations:

1) Revolute joints in any loop can be replaced by prismatic joints with no change in DOF of the mechanism, provided that at least two revolute joints remain in the loop. If all revolute joints in a fourbar linkage are replaced by prismatic joints, the result will be a two-DOF assembly.
2) Any full joint can be replaced by a half joint, but this will increase the DOF by one.
3) Removal of a link will reduce the DOF by one.
4) The combination of rules 2 and 3 above will keep the original DOF unchanged.
5) Any ternary or higher-order link can be partially "shrunk" to a lower-order link by coalescing nodes. This will create a multiple joint but will not change the DOF of the mechanism.
6) Complete shrinkage of a higher-order link is equivalent to its removal. A multiple joint will be created, and the DOF will be reduced.

Half joints referred to in the rules above are any joints other than revolute (pin), prismatic (slider), helical, cylindrical, spherical and planar joints. For example, a slot-follower (pin in slot) joint is a half joint with two degrees of freedom, very common in planar mechanisms. Linkage transformations, among other uses, can be used to transform a fully pin-jointed linkage into a more complicated planar mechanism. There is no general algorithm for when to use those principles to convert the link lengths of one type of linkage to another. However, the rules of linkage transformation are helpful for directing the brainstorm that occurs when the engineer tries to come up with a mechanism.

Another three types of transformations to consider are "living hinge" substitution, form-closed joint to force-closed joint and vice versa substitution, and linkage cognates. These substitutions do not affect the kinematic behavior of the mechanism, but can affect the cost. Living hinges can replace pin joints if both pin-jointed links experience no considerable stresses and can be made of plastic, thus making the two links one physical part. This substitution can make the linkage cheaper, but it only works if no considerable forces are transferred through the living hinge joint. Form- to force-closed and vice versa substitutions pursue the same goal of cutting costs if applicable. Linkage cognates can be generated if the initial pin-jointed linkage doesn't fit in the workspace.

The dimensions of the pin-jointed linkage generated cannot be unambiguously converted to a mechanism with multiple types of joints as described above. Rather, the transformation procedure is intended to use the dimensions of the pin-jointed linkage only as the design guide for a mechanism that could approximately trace the desired coupler curve. Also, since a fourbar linkage is already a very simple and manufacturable mechanism, it may be sufficient for the manufacturability required from the mechanism.

This concludes the design of a lock with a new coupler curve; the next step is the choice of driver.

3.3.3.3 Choice of driver

After the mechanism for tracing the coupler curve is defined, the driver can be designed. The driver can simply be viewed as a source of energy for one of the joints of the mechanism (magnetic, spring, gravity, etc), or it can be the very means to operate the mechanism (a button, a lever, etc). A procedure similar to the one described for the mechanism can be followed, with the coupler point this time being at the joint between one of the elements of the already designed mechanism and the coupler link of the driver. The joint between the coupler link of the driver and the already designed mechanism can be either a pin or a slot-follower; others are generally not recommended. As such, the driver generally consists of two parts – the actual source of energy (compliant element, user, spring, motor, etc.) and the means to convey it to the already designed mechanism. The conveying linkage can often be a dyad, generated graphically. Notice, that the slot-follower joint between the release mechanism and the lock can be form-closed or force-closed. A force-closed joint will require a spring or gravity acting on the follower to keep the joint intact (at least while the driver is acting).

3.3.4 Exact shape definition

After the mechanism is synthesized, the exact shapes of each link (including the features of the ground that the coupler is in contact with) can be determined. Generally, any link shape has to satisfy two criteria: not violate the geometric constraints, and resist the expected load with a preset safety factor. An initial determination of the shapes has to be made before the analysis for failure can be conducted, so the primary criterion at this step is the geometric constraints of the mechanism.

The outcome of this step is a set of solid models of all the elements of the mechanism. After the initial exact shapes of the mechanism components are defined, an FEA of the elements for failure can be conducted. If the FEA discovers that the solid models built fail under the applied loads, reiteration is necessary. If the factor of safety that the mechanism fails under is close to 1, then it may only be necessary to repeat the solid modeling step of the process.

After the FEA verifies that the solid models are acceptable, the theoretical stage of the design is complete. After that prototyping, physical testing, and mass-manufacturing are possible.

4 Case study

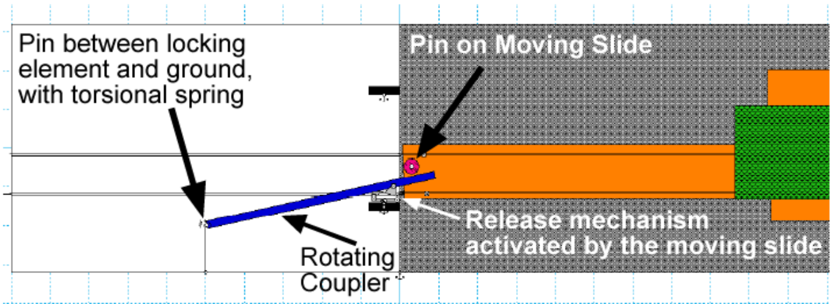

Fig. 4 Designed self-closing mechanism
(Working Model 2D model)

The design process described in section 3 above was tested, by implementing it in a case study. The customer requirement given was the need for a self-closing mechanism – the mechanism that automatically completes retraction of a linear slide when it is within 2 in of being fully closed. The problem was tough primarily due to spatial constraints (linear slide chassis are only about 10 mm thin) and heavy load (a 60 lb server) that had to be moved by two such slides. The design process was implemented and a conceptual model for a potential design with some preliminary analysis was designed over about 3 days.

The primary difference between existing similar mechanisms designed via conventional design processes and the mechanism created as the outcome of this case study was simplicity. As shown on Fig. 4 above, the designed mechanism is very simple – it consists of two pins, a short bar, a torsional spring and a bent flat spring for release. The design team arrived at this design by applying linkage transformation rules – from a near-straight line fourbar linkage to a walking beam conveyor to a Geneva mechanism to just one side of a Geneva mechanism, which is essentially what the final design is (with minor adjustments). The circular coupler curve in the plane normal to the page was used to apply the preset coupler curve methodology to design another rotating element which served as the stopping mechanism for the rotating coupler, and released it when the slide was moved to operation range. The living hinge substitution was then used to convert the rotating element to a flat spring.

The designed mechanism turned out to be not only well-performing, but also very simple and easy to manufacture. More extensive implementations may be necessary to further refine and analyze the developed process, but the case study presented here can be deemed successful.

5 Conclusions

Existing design processes are either far too general, or too complicated and unfit for small and medium-sized companies that design and manufacture relatively simple mechanisms. They also usually do not involve redesign. Because of that, a new design process optimized for such companies was developed, and summarized in the form of a flowchart. The process relied on a combination of components from several existing design techniques, processes and rules. A case study was conducted to verify the process's effectiveness and was deemed successful.

The process was only summarized in this paper. Its full description can be found at Ref. [10].

6 Bibliography

1. Norton, R.L., *Design of Machinery: An Introduction to the Synthesis and Analysis of Mechanisms and Machines*, 3rd ed. 2004, McGraw-Hill, Boston, MA.
2. Chen, L., Macwan, A., and Li, S., *Model-based Rapid Redesign Using Decomposition Patterns.* Journal of Mechanical Design, 2007. **129**: pp. 283-294.
3. Li, S. and Chen, L., *Towards Rapid Redesign: Pattern-based Redesign Planning for Large-Scale and Complex Redesign Problems.* Journal of Mechanical Design, 2007. **129**: pp. 227-233.
4. Chen, L., Ding, Z., and Li, S., *A Formal Two-Phase Method for Decomposition of Complex Design Problems.* Journal of Mechanical Design, 2005. **127**: pp. 184-195.
5. Miles, L.D., *Techniques of Value Analysis and Engineering*, 3rd ed. 1989, Lawrence D. Miles Value Foundation. Available at http://wendt.library.wisc.edu/miles/milesbook.html.
6. Central Industrial Supply Company, *Central Industrial Supply (CIS)*, 2008. Available at: http://www.ciswww.com/.
7. Chusilp, P. and Jin, Y., *Impact of Mental Iteration on Concept Generation.* Journal of Mechanical Design, 2006. **128**: pp. 14-25.
8. ARTAS - Engineering Software, *ARTAS - Engineering Software*, 2007. Available at: http://www.artas.nl/.
9. Design Simulation Technologies Inc., *Working Model 2D*, 2007. Available at: http://www.design-simulation.com/WM2D/index.php.
10. Sosnovsky, E. and Windsor, B., *CIS Slide Lock Design Process Development*, MQP Report, 2007. Department of Mechanical Engineering, Worcester Polytechnic Institute, Worcester, MA.

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