KINEMATICS MODELING OF MECHANISMS WITH SELF-ADJUSTABLE PARTS

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Abstract

The paper suggests an original method for kinematics modeling of mechanisms with self-adjustable parts based on 3D modeling. SADT-model of such a mechanism and the mathematical model of the method are presented. Implementation issues with AutoCAD are considered; the object under investigation is a spring-operated catch of a rotor production line.

Keywords: *Kinematics, 3D modeling, AutoCAD, Self-adjusted.*

1. INTRODUCTION

When considering the production of mechanical devices, we might agree that the part's overall design becomes the foundational component of all production planning. Indeed, the design process involved in creating a new product must not only include the synthesis of the new product, but also a careful design verification process as well as the optimization of each part which may make up the product as a whole. To assist us in this design phase of a product, modern engineering analysis tools such as FEM and FEA tools are readily available in many "heavy" CAD packages like Pro/ENGINEER, or CATIA. The world of design and manufacturing of today in the technologically sophisticated realm of Western nations seems to provide to engineers a working environment that only a decade ago was still a dream yet to be realized.

Even a cursory review of standard manufacturing methods reveals two distinct implementation stages of CAD in industry. First, the design process itself now revolves around *"digital drawing boards"*, which are used to generate either 2D projections or 3D models of the proposed product. The transition of this stage to the digital domain seems to be primarily complete as the use of traditional pencil and triangle methods are rarely used anymore. The second stage is *computer-aided design verification and optimization*. The transition to this second stage requires a new level of designer's skills and a profound understanding of the mathematical models behind the analysis tools. Without such an understanding it is very easy to obtain erroneous results that might lead to disastrous consequences [1].

However, having said all this, we would be remiss in suggesting that all manufacturing applications, or industrial enterprises around the world are ready for, or even eagerly adopting, engineering design or analytical tools available in high-powered CAD packages. The transition to a 3D model paradigm of design is very often prevented by the existing experience of designers who are used to thinking about the part's2D projections more than about the part itself as a component of a whole product. As one can imagine, in our world of interconnected industries and the global ownership of diverse manufacturing concerns, 2D-representations of designs are simply not suitable for many of the complicated tasks involved in engineering analysis. Development of a 3D model using Boolean operations or feature-based design is a more challenging task that requires "new thinking" [2]. The problem is further complicated by the fact that in industry few designers have the luxury of being able to take the time to stop all the current projects and learn a CAD package like Pro/Engineer or I-DEAS that has such a large learning curve. Therefore, it appears that the gulf between the design and manufacturing practices that separate the 2D and 3D worlds within industry is destined to remain wide fore some time to come. Speaking directly to this problem, LaCourse [3] wrote:

> "…what I regret most is never seeming to have enough time in the workday to fully explore all the benefits and proper techniques on my Computer-Aided Engineering (CAE) tools. Unfortunately, the pressures of meeting the customer's needs, design specifications, reviews, and deadlines of multiple projects have time and time again left me (like many in my field) seeking and accepting a path of least resistance. (p. xxxix)

2. PROBLEM STATEMENT

A detailed analysis of routine design activities at a number of large Russian engineering companies (*Tula Cartridge Works, Tyazhpromarmatura,* and *the Tula Arms Factory*) identified several common design challenges faced by each enterprise. Design solutions related to specific projects have become highly labour-intensive, and at the same time creating digital design demands that cannot be effectively solved using their existing CAD packages. These problems have also cascaded into other aspects of the production process by increasing material handling requirements and reducing time saving issues. The specific problem that we will address in this paper will deal with the design and kinematics modeling of mechanisms with self-adjustable elements (MSAE).

An MSAE is a mechanism in which some parts do not have direct mechanical links to other parts. Examples of such mechanisms would include various clutches, mechanical catches, latches, locks, manufacturing attachments, and various parts of firearms with self-adjustable parts. In all of these examples, the object being captured or held (that is, the self-adjustable element) is not initially linked to the mechanism itself. However, despite the fact that the object being captured is not part of the mechanism itself, it is important to note that the captured object must be treated like a part of the mechanism. By ignoring the captured object, the whole device becomes non-operational.

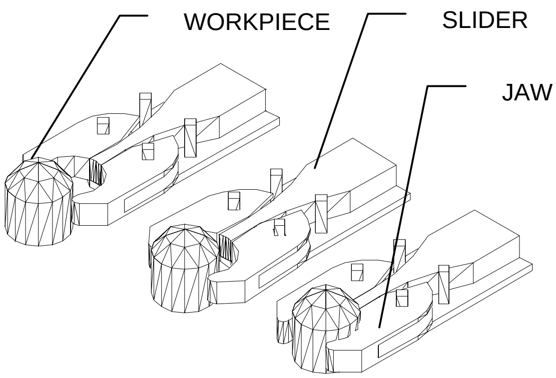

Figure 1: Capture of a production line rotor.

Figure 1 shows an example of an MSAE (a spring-operated catch for a rotor) that we will study in more detail further on. The spring jaws are mounted on a slider that is itself affixed to a transportation rotor. This unit in turn is supposed to catch hold of the object (work piece) and hold it securely in a magazine on the manufacturing rotor. The principal difficulty in MSAE design is the choice of an optimal shape of the caught parts. The designer must take into consideration several contradictory requirements. For example:

a. The mechanism should provide reliable fixing of the object,

b. There should be no impact loads,

c. The shape should be as simple as possible to decrease manufacturing costs, etc.

Admittedly, more often than not, the most common way to arrive at the potential MSAE design is through the "paper and pencil modeling" approach. Basically this means that the designer draws the positions of the parts with a certain step, and then analyses the sequence of "frames" (or, steps if one prefers) that it will take to complete one full operation of: Capture – Position – Machine – Release – Capture repeat loop. It is no doubt self-evident that such a technological approach is enormously labour-intensive, inefficient, and inaccurate as it often depends on little more than a lengthy trial and error series of attempts to conclude the right steps required. Another common option, that of making and testing a prototype, while certainly more effective, is not only extremely labour expensive, but ties up expensive equipment in down-time, and significantly slows the entire process of production planning.

Unfortunately most kinematics modeling systems (i.e. T-Flex, or Cosmos) that work well with traditional mechanisms where there are rigid or elastic links between the parts are helpless when we have a MSAE. Why? The reason lies in the fact that you cannot effectively introduce into an existing model an independent element that has to appear from nowhere. Further, if a highly complicated part shape is required this in turn makes direct calculation of the part's position(s) using theoretical mechanics methods no less labor consuming than the above-mentioned paper-and-pencil modeling.

So in many nations of the world, where technology is still in an emerging role in industry, what do we have? We have systems being used in the digital design process that either cannot compliment the needs of diverse manufacturing concerns due to dimensional differences (2D verse 3D). We still have manufacturing and design teams where designers cannot break out of their two-dimensional paradigms due to a lack of training, time, or money. And, we have a dearth of computing systems robust enough to create the type of technological environment required to solve many of the mathematical challenges that we may face in an attempt to create functional MSAEs. Without a doubt, there is a demand in budding industrial nations for a new method of MSAE modeling that would be efficient, fast, and would eliminate to need to generate a physical prototype.

3. MATHEMATICAL MODEL OF MSAE

Using relational algebra notation a MSAE is described by the following equation:

$$\sigma_{(N_0=0)} R \neq \varnothing$$

Where,

R = The relation containing information about all the parts of the mechanism

N_0 = The number of links of each part to other part in the initial position of the mechanism, and

σ = An operation of data selection with a specified criteria

Both Amalnik and Marka [4] proposed original approaches to mechanisms description based on SADT-diagrams. Following such an approach it is possible to introduce a SADT-diagram of and MSAE such as the one shown in Figure 2**.**

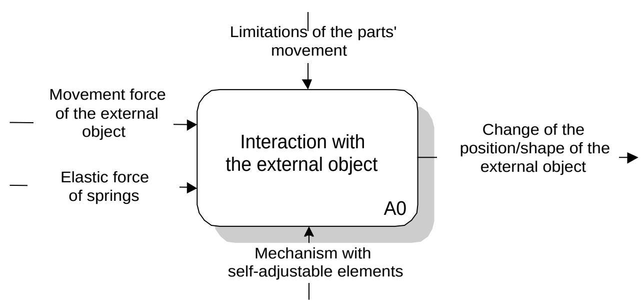

Figure 2: SADT-diagram of a mechanism.

Such a diagram allows the designer to define the specifications of a model including spring force and movement limitations considerations, etc [5].

4. TOUCHING DETECTION OF PARTS

Regardless of the arguments heretofore proffered, it is natural to use solid modeling for kinematics modeling of MSAE. While profiles of the various parts might have variable thickness (that is why flat models are generally unsuitable for modeling), the real difficulty arises when the system has to determine the positions of the parts that touch the self-adjustable object. Specifically, it is really a problem of detecting the "moment of touching", or contact, of the two (or more) solid objects. To detect the moment of touching we will use the (2) operation. This produces a new solid model M_3, being the intersection area of M_1 and M_2.

$$V(M_3 = M_1 \cap M_2) \to 0$$

Where,

$V(M)$ = the function which calculates the volume of the M solid model

Now it is possible to find the moment of touching with any predetermined specification for accuracy. The elastic force of the spring is considered in removing corresponding clearances between the parts and, if necessary, in calculating the distribution of external driving force between the springs [6].

4. IMPLEMENTATION CONSIDERATIONS

The major of the work upon which this research has been based has been conducted in Eastern Europe and specifically within industrial enterprises in various cities in the Russian Federation. Based on the need for a technologically most sophisticated system of design and production processes, this work has attacked the problems stated in this paper from a perspective that many in Western nations may find unusual. While many of the problems could have been addressed successfully by using the more accepted robust CAD system such as Pro/ENGINEER and the like, there are other considerations that made such a choice impossible and indeed, inconsequential when it came down to meeting the problem head-on. Readers may immediately believe the approach taken was purely a financial one due to the struggling economies in which most Eastern European industries operates. While that is certainly a consideration it is actually a small one. Due to the proliferation of various forms in which all software titles appear in Eastern Europe, at extremely low prices, the purchase of any software is really a non-issue in this project. What is a far more weighty issue is being able to effectively use resources already in place to their full potential. Most designers and engineers in Eastern Europe are still being introduced to CAD software packages in various forms. Jumping into parametric packages with huge learning curves is just not within the grasp of most of the people involved in industry at this time.

Even a casual review of industrial design teams in Russia will show that the vast majority of designers are very well versed and comfortable with AutoCAD. Therefore, it was decided to attack this project by developing an AutoCAD-based kinematics modeling system. Based on finding and work done in previous years at Tula State University on creating a parametric modeling feature that would run inside AutoCAD, the system developed used an AutoLISP application created for AutoCAD Releases14 and 2000. The final version is currently in use within the design department of the Tula Cartridge Works as of the time of this writing.

The system models the above-mentioned clutch for a rotor production line (as shown in Figure 1). The touch detection procedure is based on the solid intersection operation with the parts then being moved along at a specified step value. If a new solid can be created by intersection, the parts are moved a step back and the process is repeated with a new step being 0.5 of the previous one. This approach allows any required accuracy of modeling to be easily obtained. Note that the clutches are designed with the accuracy up to 0.01mm. As the step becomes less than the specified accuracy the system assumes that the parts touch each other. Mathematically speaking the system minimizes the volume of the body formed by intersection of two or more solids. As a result the system generates a sequence of frames with dimensional and angular parameters specified on each step. The designer, or the system itself, then compares the values of the parameters with the experimentally measured ranges. For example, for the clutch it is highly important to avoid impact loads. On each frame (the standard step is 1^o) the system indicates a so-called "attack angle". Experimentation during this problem revealed that the optimum attack angle should belong to the $10..12^o$ range, otherwise impact loads would destroy the plastic jaws. If the angle exceeds the specified limits the system produces an alert message and the proper adjustment can be made.

5. CONCLUSIONS

This paper has attempted to address a variety of issues that are currently being faced by industrial enterprises in many nations of the world. The experiences and needs of what has been detailed as to the work being done in Russian factories is in no way unique to that nation alone.

As diversity is likely to always exist in the way that manufacturing teams address the needs of their companies, it would be foolish to try and create a "one size fits all" paradigm to meet the needs of solid and surfacing modeling, or the generation of MSAEs by all manufacturers. The fact is that we have large, technologically sophisticated western corporations often cannot decide within their own organizations as to which software to use, or how problems can be solved across platforms as each department and supplier has a strong argument for their approach.

The purpose of our work has been to detail options that are available to those companies that wish to consider alternatives to finding an efficient solution to the problems associated with MSAE modeling. Further investigation is aimed at integration of the MSAE modeling module into a unified CAD/CAM/CAE environment.

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