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Design of double toggle switching mechanisms

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ABSTRACT

Toggle mechanisms are ubiquitous in electrical switches. However, literature for their mechanical design is scarce. This paper defines and classifies the toggle phenomena observed during switching. The concept of double toggle introduced in this paper enables a systematic screening of kinematic structure for the suitability in high performance switches. Seven structural and three kinematic criteria are identified for this purpose. It is also demonstrated that each such feasible kinematic structure lends itself to multiple physical embodiments. Therefore, the theory and procedure presented in this work can be used for design of numerous kinematically distinct mechanisms. One representative mechanical embodiment for a novel double toggle switch, including mass and geometric shape of links has been included in the paper. The switching behavior of the design is validated using Pro/Mechanism™.

1. Introduction

Electrical switches are mechanical interface to an electrical system which enables closing and opening of the circuit through the user input. An electric switch can be as simple as a knife switch (Fig. 1a) where a conducting *pivoted lever* is directly manipulated using an insulating knob by the operator to make or break a circuit. The fixed contact is typically U-shaped which also acts as a clip to hold the lever in position when the circuit is closed. In a switch there is a link for user input, called the *handle* which moves a current carrying member (*follower*) to make a specific region on it called *moving contact*, come in contact with another specific region on a fixed link called *fixed contact*. These contacts are made of special geometry and material suitable for good electrical performance under repeated impacts during making and breaking of the circuits.

Early developments ([1] in 1911) indicate use of an external spring to maintain the position of the handle in one of the two states, ON and OFF. The moving contact here was mounted on an elastic strip (beam) which was deformed by the actuation lever to establish contact. The switch ([2] in 1952) uses the same type of contacts, but the elasticity of the elastic strip itself is used to maintain the ON and OFF states through the cam profile used in the operating lever. Although this is named as a toggle switch and it mentions about quick closing and breaking of the circuit, within the context of the patent, its effectiveness is not very clear. Nevertheless, it is one of the earliest to mention about mechanistic implementation of the speed of operation; however, the need for such behavior has not been identified. The use of heavy duty, dedicated, actuation springs can be found in [3] (1935). However, the fixed contacts used here are U-shaped as in knife switches. Kinematically, a knife switch is a simple lever, [3] is equivalent to a four-bar linkage and [1] is equivalent to a six-bar Watt-chain; all single d.o.f. kinematic chains. The spring in [1,3] is said to work over the 'dead-center' configuration. Mechanism enabling such phenomenon is referred to as bistable, snap-action and toggle mechanisms in literature. In this paper we preferred to use the term 'toggle'.

Although numerous patents of switch mechanisms are available, literature on the systematic mechanical design of switches for prescribed functional requirement is limited. Most of the studies reporting performance related issues, focus on electrical and electromagnetic phenomena associated with the functioning of selected switching mechanisms, which are irrelevant in the present context. Within the context of mechanism design, a method to optimize the shapes of components in a given mechanism

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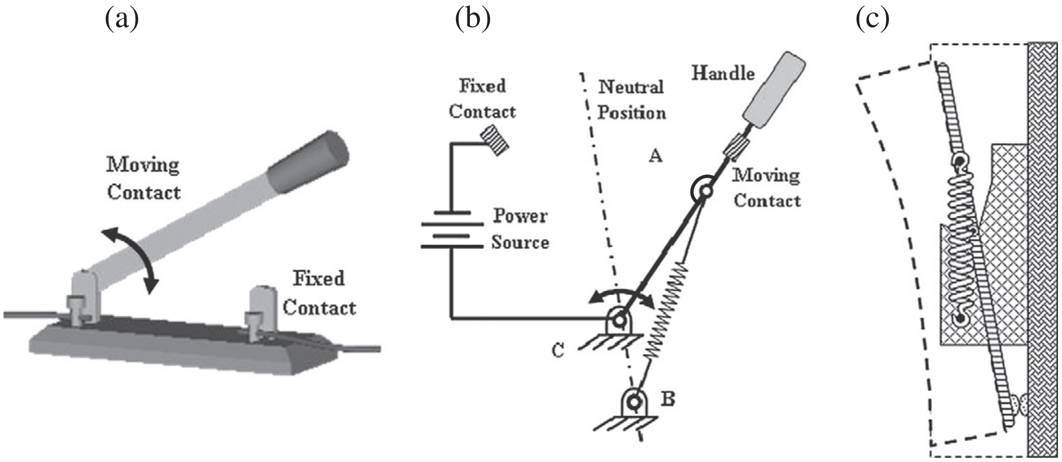

Fig. 1. Common types of switches. (a) Knife Switch. (b) Schematic toggle switch. (c) Rocker switch.

using a multi-body simulation package is presented in [4]. Methods to achieve efficient breaking by effective usage of electromagnetic repulsive force generated between two contacts have been reported in [5,6]. [7] presents the dynamic model of a low-voltage MCCB operating mechanism created using ADAMS. [8] presents a simulation based method to analyze the interruption process of MCCB. Through simulation based parametric study, it was demonstrated in [9] that the influence of the kinematic configuration in the performance of a switching mechanism, is more pronounced than the dynamic property of a similar system.

Towards generation of the kinematic alternatives, [10] performs a structural analysis on the operating mechanism of mechanical switches. Although it enumerated numerous simple mechanisms with spring loaded bistable states, it did not give any method for generation or generalization of the solutions. Dyad synthesis method for a five-bar variable topology mechanism is used in [11]. It identified multiple possible topologies for circuit breaker applications. A methodology for the behavior of the operating mechanism of a circuit breaker using Boolean functions of two variables is presented in [12]. The energy states of the operating spring are determined from the associated Truth Table which in turn determines the sequence of operation. [13] characterized the so called bistable mechanisms using energy and stability. The idea was used to extend the concept to compliant mechanisms via pseudo rigid body models. The discussions in the paper are limited to four bar equivalents. The structural and kinematic syntheses of controllable circuit breaker mechanisms have been discussed in [14] where the strategy of function assignment to different links and joints for selecting a suitable mechanism for the given purpose is under focus. Although it enlists a number of functional requirements which are used for evaluating suitability of a concept, the rationale behind the conditions are not explained. Moreover, the paper focuses on inclusion of different control inputs, which decides the d.o.f. of the kinematic chains. There is no systematic methodology found for design of a switching mechanism comprehensively. [15] presents a systematic graph theory-based method for the topological synthesis of planar metamorphic mechanism. It gives a way to express topological constraints for metamorphic changes in the form of subgraph constraints. The theory developed here is applied in the design of low voltage circuit breaker mechanism.

The present paper focuses on the structural synthesis for the switching mechanisms using the strategy of function assignment. It emphasizes the importance of the toggle phenomenon, introduces the notion of double toggle in multi d.o.f. mechanisms and shows how such mechanisms can be designed for different switching patterns. The paper introduces the notion of active and passive sub-chains to systematically derive the options for the function assignment and uses them for developing the set of structural and kinematic conditions to be satisfied by a mechanism to exhibit double toggle. The working of the operating mechanism of a few commonly available switches has been critically studied from the perspective of toggling to evaluate the designs. The theory developed is then used for the ab initio design of a new double toggle type switching mechanism.

The paper is relevant for all manually operated toggle switches. More specifically, the paper purely focuses on the switching mechanism of the circuit breaker. The tripping mechanism and other fault sensing techniques are potential future studies and out of the scope of the present paper. An optimization method to satisfy the stringent demand on performance for a specific switching application is also not in the scope.

2. Characterization of toggle in switches

When a spring is attached between two links in a single d.o.f. mechanism, its potential energy is a function of the configuration. If this function has a maximum at any configuration, *C*, then the mechanism would absorb energy till this configuration and release energy beyond this configuration. This would happen when the distance between the two anchor points is maximum or minimum. At configuration, *C*, the system can neither absorb nor release energy; hence an external force