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Design methodology and case studies in actuator selection

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ABSTRACT

Actuators are important work performing devices, incorporated within many engineering systems. There is a small core of actuator technologies that are frequently used by designers when in fact a wide range of possible solutions exist. Attempts have been made to categorise and compare actuators based on material performance, when in fact stimulus generation and actuator configuration are much more effective and practical criteria. Performance based figures of merit and user requirements analysis are further augmentations of the actuator selection methodology presented, useful to designers when choosing actuation solutions from existing as well as emerging technologies early in the design process. Three case studies in actuator selection are presented to demonstrate the approach.

1. Introduction

An actuator is a device that converts an input energy into useful mechanical energy. To make the resulting mechanical energy useful, the actuator must be able to respond to a signal or stimulus, and must be able to deliver the work in a certain amount of time, and in a controllable manner [12,15]. The work produced is defined by the force and stroke; typical requirements of all actuators. It is therefore considered that an actuator is a combination of a technology and its stimulus arranged in a particular configuration. Fig. 1 shows the main elements of an actuator in its basic elemental form. Further, the material exhibiting the actuation phenomenon is configured in such a way to provide work in a useful direction influenced by packaging and fabrication requirements. The complexity of the final actuator will vary by virtue of the complexity of each of these elements, and this will in turn dictate cost, performance and functionality. An actuator, as defined here, does not include any other discrete device such as a leverage mechanism, but together with this element, an engineering system is then created.

Certain combinations of mechanical energy and stimuli, manifested as popular existing actuators, are established in industry e.g. pneumatics, hydraulics, piezoceramic actuators, solenoids and bi-metallic devices. They cover a very wide range of performance requirements, many variants of which were originally borne from specific and niche applications. However, gaps in performance (usually defined by application) can potentially be met through the use of new and novel actuators. Filling these gaps will also potentially yield large cost savings in the long-term. Many engineering companies encourage their staff to keep abreast of new technologies and some are aware of new materials and their potential, although there is reluctance to pursue the integration of these more modern solutions for several reasons. Development costs, availability of design knowledge, experience of use and market exposure all concern engineers because the risk of a product development failing will increase. A particular concern is that a new technology does not have a long enough proven industrial track record. The first question asked is usually, “Can you show me where this product has been successfully used for the past five years?” Rapidly, systematically and logically identifying actuation solutions would aid designers and engineers.

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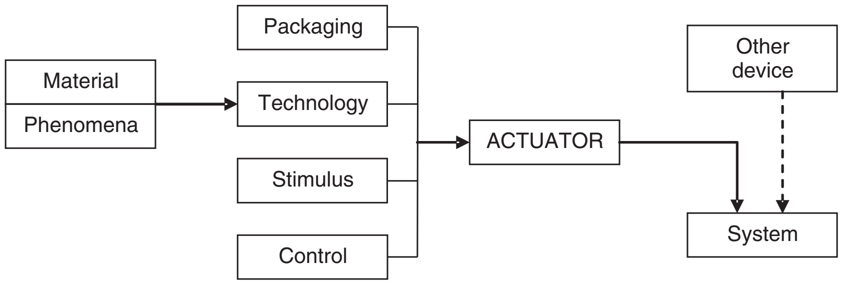

Fig. 1. Composition of an actuator as part of a system.

Currently, selecting actuators is not a trivial task, mainly because performance data is not consistently structured across industry and is described by a multitude of metrics not related to specific design requirements. In particular, performance data from the research community for newer materials is usually presented for the material only, not the material manifested as an actuator, and recent studies make many assumptions regarding how the technology is manifested, only focusing on technology performance. This is perhaps acceptable if one wishes to compare technologies, but omits how actuators are manifested. A machine designer would not be able to fully justify what technology should be used for an actuator from existing comparisons. This is because existing comparisons do not systematically approach the subject of the actuation technologies' implementation into a product.

In this paper, an actuator selection strategy is developed, used for selecting actuator technologies from those established in industry, and uses a prioritised 'figures of merit' approach to aid selection based on force, stroke and frequency together with a user requirements analysis. The approach is constrained to linear actuation technologies for conciseness, and is demonstrated through a series of industrial case studies. It is timely to carry out such an investigation, as many new and novel technologies are reaching a stage of development where they may be integrated into industrial actuation solutions. Some of these Emerging Actuator Technologies (EATs) may well have the potential to replace the more conventional if key performance attributes are exceeded.

2. Actuator technology categorisation

2.1. A review of existing actuator categorisations

The first stage for developing an actuator selection approach is to consider the ways that actuators may be categorised. Generally, categorisations make the interrogation of objects, products or phenomena etc, more manageable for the user. The end use of an actuator technology categorisation is for the effective comparison (from an engineering perspective) of what the market could possibly provide. Existing studies that categorise actuators are few, and although mentioned regularly [5,9,12], none pay close attention to the mechanism used to stimulate movement of an actuator and in fact, it is difficult to find any kind of categorisation as apposed to a simple list. Translational and rotary configurations of actuators are considered by Pons [12]. Rotary actuators rely on some external geometry to constrain motion to a cyclic rotary type, and whether phenomenological or based on an active material, the natural, fundamental motion of an actuator is always linear, and as such, rotary actuators are just complex configurations of linear actuators. This is not to say that rotary motion will always be more inefficient than linear.

Pons [12] also lists what are described as "input energy domains" as being a method of categorising actuators. Of course, most actuators will use electrical energy, though those technologies that use an input energy domain of another type e.g. magnetism, will usually require local energy conversion, such as a solenoid's coil. Also referred to in this reference are "hard" and "soft" actuators. Hard actuators can push and pull, whereas soft actuators can only pull. This concept is not considered useful to the engineer, since simple reconfiguration of an application can usually negate the requirement of this categorisation. Zupan et al. [15] focus on the energy source of the actuator as a possible type of categorisation. However, an engineer is unlikely to be interested in the power source, rather than what he needs to input to the actuator in order to get out controllable work. This makes the distinction between energy source and stimulus somewhat vague, because for those actuators that require an energy converter, they are different.

2.2. Actuator categorisations useful for selection

Two engineering requirements that are useful to the actuator practitioner are stimulus type and actuator configuration. Stimulus generation must be present for an active material to be used as an actuator and the addition and type of local stimulus generation can severely influence actuator performance. The possible configurations for an actuation technology have a fundamental relationship to the way that useful work is produced, possible mechanical advantage mechanisms applicable, force translation and motion direction options. Table 1 shows the main groups of technologies categorised by the primary actuating effect caused by external stimuli. This categorisation is interesting, though perhaps not so useful to an engineer. All actuators can