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Motor Selection in Mechatronic Systems Using 2k DoE Method

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Abstract: Mechatronic systems are used as control and drive units in many engineering applications from space technology to robot arms. The main drive units of mechatronic actuator systems are the DC motors. The selection of motor to be used in the systems is an important task in projects. The most suitable motor, which answers the requirements of the project, should be selected. In this article, the studies in the scope of selecting the motor for the mechatronic actuator system of a given capacity are disclosed. Unlike the related studies in literature, in this study Design of Experiment (DoE) method is used. 2k factorial methods have been used as a DoE method. With 2k factorial methods fewer tests conducted according to the full factorial method that uses combinations of all inputs and selection of most suitable motor for the requirements is succeeded.

Keywords: DC Motor, Design of Experiment, 2k Factorial Design, Motor Tests.

1. INTRODUCTION

High reliability, high availability and high power density are expected from actuator systems used in aerospace technology. Mechanical actuator systems have been used for many years especially in aircraft (Wenping, 2012). Together with the development of electric motors, majority of mechanical systems left their places to the electro-mechanical and electro-hydraulic actuator systems. Due to the characteristics of the electric motors, faster and more efficient systems with the smaller volumes were obtained. Besides the dimensional and efficient advantages of electric motors, they have the clean energy option due to working with electricity (Kan, 2013).

Air pollution has become one of today's most important environmental hazards. One of the major causes of pollution is gas emitted by petrol-driven vehicles. In this context, automotive companies have started working on electrical vehicles (EV) and hybrid electrical vehicles (HEV), which emit less harmful gases. One of the basic elements of these vehicles is the electric motor. Direct current (DC) electric motors are widely used in these vehicles, from sunroof to the air conditioner system (Kan, 2013). As electric motors need electrical power, another critical sub-system of EV and unmanned aerial vehicle (UAV) systems is the battery system. Total distance, that vehicle covers, is limited by the battery. Most of the energy is consumed by the electric motors on vehicles. Therefore, researchers are working in order to achieve maximum efficiency from the motors (Prasun, 2013). To determine the type of a DC motor used in actuators in EV and UAV systems, many parameters related to the motor need to be tested under different loads and in different environmental conditions. A few studies about the motor selection process in the literature are given below:

Changhw Choi et al, have studied on motor's choice for a robotic manipulator used in industrial applications. They used the normalization method in their studies and compared different alternatives by measuring the speed responses of the motors under load (Changhwan, 2007). Jonathan W. Sensing developed a framework in order to examine the impact of the acceleration and torque on velocity values in the scope of choice of the motor to be used in a robotic actuator (Jonathan, 2010). Darren Lance Gabriel et al. studied the test bench they have developed to choose the DC motor to be used in Unmanned Aerial Vehicles (UAV) and they determined the appropriate one by comparing the efficiency of the motors at the end of the tests (Darren, 2011). Ajay Babu and S. Ashok used the algorithm they have developed in the selection of motor for hybrid electrical vehicles. The algorithm examines the relationship between power and speed of the motor (Ajay, 2012).

Test procedure for determining the appropriate motor type becomes more difficult as the cost and the time due to availability of many different alternatives. There are many factors to be tested, which increase the test combinations and therefore the time spent for analysing the test results is also extended, too. One of the methods used to make the appropriate selection by reducing the number of tests is the Design of Experiment (DoE) method. DoE is used in many

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areas from finance to medical science. In this paper, it is objected to select most suitable motor type for the system by DoE method in DC motor selection for mechatronic actuator system tests. The study is considered as a sample for other research studies on mechatronic systems in choosing motor, sensor, and etc. components. In this study at first, the DC motor selection criteria are defined. Then, DoE method evaluating the criteria is determined and designed. According to the DoE method designed, tests are performed and the results are recorded. Finally the obtained test results and the analysis are given.

2. MECHATRONIC ACTUATORS

During the planning and design phases of a mechanical actuator system project, the type of actuator to be used should initially be determined. This depends on several factors such as space constraints, maintenance requirements and available power sources. Mechatronic Actuators (MA) have an advantage over Hydraulic Actuators (HA) with respect to maintainability, cost and safety (Edward, 2009 and Muhammad, 2012). This makes them highly desirable in systems with these considerations. MA system architecture is shown in Fig. 1.

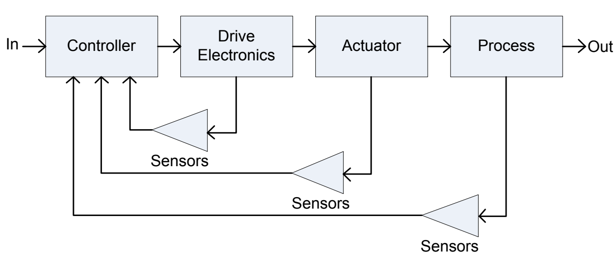

Fig. 1. MA system architecture

An electrical actuator is at the heart of an MA system, so the selection of a suitable actuator is critical to system performance. In this study, a brushless DC electrical motor is used as an actuator.

3. DC MOTOR SELECTION PROCESS

Before moving on to the selection process itself, the requirements for the drive should be defined. Some of these are the required torque, speed, and acceleration. Mass inertias, load durations and operating temperatures should also be determined. Moreover, power source available should also be considered regarding maximum voltage and current. Generally the torque is transferred using mechanical transfer mechanisms such as gears, so this is also part of the calculation process (Maxon, 2013).

The expected no load speed is calculated using (1), then (2) is used to check if the required motor speed can be achieved at a given load.

$$n_0 = k_n V_{\max} \qquad (1)$$

$$n_L = n_0 - \frac{\nabla n}{\nabla M} M_L \qquad (2)$$

Where, k_n is the speed constant, V_{max} is the maximum voltage supplied by the power source, M_L is the load torque, n_0 is the target no-load speed and n_L is the loaded speed.

The motor current that should be provided by the power supply can be calculated in (3) using the torque constant k_M and load torque M_L.

$$I_{mot} = \frac{M_L}{k_M} \qquad (3)$$

After defining the requirements, a motor, which will meet these requirements, is identified. If the capability exists, the motor can be designed or it can be acquired off the shelf. In either case, the parameters (i.e. current, torque, speed, acceleration etc.) should be verified under varying temperatures and loads to see if the product satisfies the requirements.

As part of this study, various motors (listed in Appendix) are acquired and they are tested under the following conditions:

- changing loads between 0 – 1 Nm using an external loading motor,
- changing voltages between 24 – 48 VDC using and adjustable power supply,
- changing temperatures between -40 – 65 ºC using temperature controlled test cabins.

Speed (rpm), acceleration (rpm/s) and current (A) data are collected as test outputs, which are to be used in verification.

Usually, some test conditions are determined as the designers see fit, and full factorial tests are designed using these values. However this makes the process highly dependent on the experience level and skill of the designer. If there are not enough test points, the test results might not represent the actual system. Moreover, if the tests are done too extensively, it will bring unnecessary time consumption and added costs to the process. Also, as these tests must be repeated for each motor acquired or designed, the effects are multiplied.

In this study, we propose using established statistical methods, in particular the DoE methods, to design a test, which will verify the motor parameters properly with enough test points. Then statistical tools are used again to analyze the output data.

4. DESIGN OF THE VERIFICATION TESTS

To verify the parameters and choose a suitable motor, a 2k factorial design is implemented with center points. This means that each condition will be tested under two levels, and center points will be added to see if the effects of the conditions are non-linear. As there are three test conditions, each with two levels (2^3) and three center points, a total of eleven test points are defined for each motor to be tested as depicted in Table 1. If a design with three parameter levels were to be used instead of a 2^k design, number of test points would increase to 3^3. 2^k factorial design is very useful for preliminary analysis, as it allows the testers to examine the main effects and their interactions quickly. If secondary tests are required, unimportant factors can also be removed to save time.