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A review on recent research trends in servo pneumatic positioning systems

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ABSTRACT

Servo pneumatic systems are widely utilized for obtaining accurate position control in many industrial drives. Such technology has the potential to replace electro mechanical and hydraulic drives in many applications. The main drawback of this technology is the high nonlinear nature of pneumatic drives which affects the system dynamics. It is very necessary to enhance the pneumatic drives by reducing its stochastic nature. The major causes for the non-linearity in pneumatic drives are owing to the pressure dynamics inside the pneumatic cylinder chambers, the frictional force variations and the compressed air flow rates through the valves. In the present study, an endeavor has been made to perform a detailed survey on various aspects in the efficient position control of the pneumatic cylinder. The history, applications, performance tests, component selection, modelling and accurate control of the servo pneumatic systems have also been discussed with the aim to improve the efficiency and the positioning accuracy of the linear pneumatic drive. It has been inferred that a lot of research attentions has to be given for enhancing the performance measures in servo pneumatic positioning systems by reducing the nonlinear nature of the pneumatic systems.

Contents

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1. Introduction

1.1. Pneumatic systems

The pneumatic actuators offer numerous advantages such as cleanliness, low cost, high power to weight ratio, easy maintenance, safety, anti-explosion, long working life. But the accuracy of the actuator is affected badly by its nonlinear characteristics. Pneumatics commonly refers to the study and application of pressurized gas for producing the mechanical motion. The term pneumatics is originated from the Greek word *pneumos* which means to breathe. This complicated system has been attracted by many researchers all over the world with the potentials to the industrial applications. Air based actuation is favoured in industrial sectors owing to its easy availability and non-polluting nature. The advantages of the pneumatic drives are as follows [1],

- Pneumatics is a safe and clean technology due to its usage of compressed air only.
- It is comparatively a low cost technology and requires low maintenance.
- High speed linear motion is achievable without additional mechanical transmissions.
- High weight to force ratio.
- Prolonged intense operation without risk of higher temperature operation and a broad working temperature range.
- High mechanical efficiency and long working life.
- The operating cost is low as it requires only compressed air energy.
- It can be operated in wet, dusty and chemically aggressive atmospheres without the risks of fire or explosion.
- The pneumatic actuators can be operated in the presence of radiation and electromagnetic fields, as well as mechanical vibrations, where many other actuators fail.

1.2. Servo pneumatic system

Pneumatic actuators are used in batch automation of sequences and continuous control. Conventionally the pneumatic actuators are used for motion between two defined stops. The electro pneumatic servo drives are being employed for expanding the capabilities of pneumatic drives to be used as a multi-position actuator. This type of servo pneumatic technology is generally feedback based closed loop control system. The significant problem of such drive is nonlinear nature on determining performance measures. The nonlinear characteristics such as nonlinear frictional forces, the thermodynamics of the air pressure in the chambers of the cylinder, time varying load, nonlinear valve characteristics makes the servo pneumatic system more uncertain. The pressure within the pneumatic cylinder, the frictional force, and the compressed air flow rates through the chokes of the pneumatic drive are varying in nonlinear nature. The nonlinearities in the valves are resulted in poor damping, low stiffness, limited bandwidth which adds the complexity to the system.

1.3. History of servo pneumatic systems

Beater [1] described a detailed history of the servo pneumatic system. Shearer [2] discussed about the continuous pneumatic position control to enhance the performance measures. An attempt has been made to analyse the closed loop position control of pneumatic systems under higher pressure air supply. Burrows and Webb [3] used the root locus technique to analyse the stability of these closed loop pneumatic positioning system. Burrows [4] presented an extended study on position stability of the servo pneumatic system. Barker [5] used Luenberger observer algorithm to reconstruct the velocity and acceleration signals from the measured position signal. It has been found that the additional feedback of these two signals significantly improved the performance of the linear pneumatic actuator in a missile flight control system. It has been found that there has been almost two decades to develop this technology to a point where off-the-shelf controlled pneumatic drives can be regarded as standard components. These drives had not been required any special training in control system design to be operated successfully [6].

1.4. Applications of servo pneumatics systems

Servo pneumatic system has a wide range of applications in industries and other automated systems. Pneumatic actuators are widely used in the fields of automation, robots and manufacturing. This technology is very useful for the physical system manipulation and rapid motion of mechanical objects and also in assembly, monitoring, packing, stacking, clamping, and fixing of various manufacturing products. Backe [7] presented a detailed study on the application of servo pneumatic drives for flexible mechanical material handling techniques. Wang et al. [8] utilized the servo pneumatics for packaging food products as it is a clean and efficient technology. Moilanen [9] utilized the servo pneumatic drive for material testing system in high temperature water and irradiation environment. Arreguin et al. [10] developed a servo pneumatic drive for flexible manipulating robots lines as the force to weight ratio is higher. Bobrow and McDonell [11] designed light-weight and inexpensive pneumatic robot driven by servo drives. Gauchel et al. [12] developed a gripper with individually movable jaws driven by a servo pneumatic cylinder. Fischer et al. [13] developed a prototype of an MRI-compatible manipulator driven by pneumatic servo drives that can be used for needle placement. Hesselroth et al. [14] designed a soft arm for robots actuated by pneumatic drives. Zhang et al. [15] designed a three axis climbing robot with a servo pneumatic drive for each axis. The servo pneumatic technique has the potential to replace less efficient electromechanical and costly hydraulic actuators in many applications.

1.5. Characteristics of servo pneumatics systems

Accuracy and speed are the most important characteristics for an actuator. The position change over test and trajectory tracking test are two main types of tests for evaluating the performance of the servo pneumatic positioning systems. The position change over test or a point to point changeover tests are conducted by making a step change in the reference signal either from 0 to 100% or from