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Optimum Tuning of 1&2-dof TID-F Controllers for a MAGLEV System with Experimental Validation

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***Abstract*—In this work, a rigorous comparative study is carried out between the 1-dof tilt-integral-derivative controller with filter (1-dof TID-F) and the 2-dof tilt-integral-derivative controller with filter (2-dof TID-F) for simultaneous stabilization and precise position control of a laboratory scale magnetic levitation system (MAGLEV). TID controller is basically a modification of the traditional PID controller in which the proportional gain is swapped out for a non-integer order tilting term. Again, in series with the derivative term, a fractional order (FO) filter is introduced to reshape the frequency response curve because FO system has tremendous potential in modelling and control of inner dynamics of highly non-linear and unstable physical system like MAGLEV. For designing and tuning of 1&2-dof TID-F controller parameters a modern soft computing based nature inspired optimization algorithm, popularly known as, Moth Flame Optimization is deployed. Various simulation and real-time results demonstrate that the proposed 2-dof TID-F controller improves time and frequency domain performance metrics while also providing superior reference input tracking ability.**

Keywords— 2-dof controller, fractional order control, magnetic levitation system, moth flame optimization, TID-F controller

I. INTRODUCTION

One of the fascinating innovation of the contemporary engineering technology is the Magnetic Levitation System (MAGLEV) [1] which has been the centre of focus for the researchers all over the globe. MAGLEV system has been emerging as a whole new area of scientific interest which demonstrates the levitation and suspension of ferromagnetic objects in free space aided by strong electromagnetic fields. To suspend the object at a desired position, an equilibrium condition must be established between the lifting electromagnetic force and the down pulling gravitational force. To nullify the effect of gravity, no physical support is utilized. According to the available theories, magnetic levitation system can be of two types. One which requires attractive magnetic force for suspension, is commonly known as the electromagnetic levitation system [2] and another one which utilizes repulsive magnetic force for suspension, is commonly termed as the electrodynamic levitation system [3].

Present day industries and human civilization have been greatly benefited by the application of MAGLEV technology. Among the many applications of MAGLEV system few noteworthy mentions are high speed MAGLEV vehicles, frictionless magnetic bearings, vibration isolation of sensitive machinery, magnetic wind tunnels, aircraft Launch pads and Nano metric precision industries etc. Although MAGLEV system has numerous advantages, but if one derives the internal model and analyses the system dynamics then it is found to be highly nonlinear and inherently unstable. Due to the nonlinear behaviour, system performance severely deteriorates for a small perturbation of equilibrium point and the system becomes unstable beyond a certain operating condition. Therefore, control system engineers encounter several challenges and difficulties while designing controllers for controlling and stabilization of the unstable and complicated MAGLEV system.

Based on the existing control literature, a piecewise linear control scheme could be an effective solution to take care of system nonlinearities [4]. Another way, one can implement two loop control system with inner PI controller and outer Lead controller [2]. Similarly, PID controllers [5] are also able to provide satisfactory control performance in the neighbourhood of chosen operating point. But for wide range of operating conditions, classical controllers cannot perform effectively and efficiently.

Therefore, tuning of PID controller based on meta-heuristic optimization algorithms is adopted by many researchers. GWO based PID tuning methodology is proposed in [6]. Some real-time application of various optimized PID controllers for MAGLEV is demonstrated in [7]. Tuning of PID controller parameters employing multi objective Genetic Algorithm is proposed in [8]. Some have utilized PSO technique [9] to suspend MAGLEV vehicle. The dynamic performance of conventional integer order PID (IOPID) controller is further enhanced by applying fractional order calculus to design and formulate fractional order PID (FOPID) controller. Digital FOPID design with pole/zero approximation technique [10] is devised for MAGLEV system. In [11], tuning of FOPID with time domain parameter optimization is shown. Design and analysis of FOPID controller is investigated in [12] based on Ant Colony Optimization. Stability analysis based optimum PID parameter tuning [13] has also been studied. PSO based FOPID design has clearly been demonstrated in [14]. Practical implementation of optimized FOPID controller through the Oustaloup recursive filter [15] is able to provide excellent robust performance for MAGLEV hardware prototype. In [16] an adaptive fuzzy PID compensator is implemented for MAGLEV system. FOPID tuning methodology incorporating numerical search optimization [17] is demonstrated and implemented in magnetic bearing system. Modification of FOPID controller by using FO derivative filter [18] has significantly improved MAGLEV's robust characteristics.

Recently a lot of research effort has been put in two degree-of-freedom (2-dof) control architecture [19] which are better than 1-dof counterpart in many aspects. 2-dof PID controllers can reduce the overshoot, they are less sensitive to disturbance and noise signals [20] and have better set-point tracing ability [21]. Many applications of 2-dof IOPID and FOPID controllers are found for MAGLEV systems [22, 23].

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