A Root-Mean-Square-based Measurement to Optimize a Parameter in the Control Systems Design

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***Abstract*—In the classical control systems design, a parameter is typically determined by the system's time response or frequency response. A standard unstable double-integrator plant with a spring constant K and a mass M is a perfect illustrative example. A stabilizing damper B is determined by setting the time-response to be qualitatively fast and non-oscillatory, which is basically setting the damping-ratio of the second order system equal to 1. The time-response is the system's response to a certain input, such as an impulse-function, a step-function, etc., not its response to an arbitrary disturbance, which is more likely to occur in the field The root-mean-square-(rms)-based approach introduced here allows a designer to estimate a better parameter to minimize an objective function. The objective function is a combined quadratic function of the "error" and the "effort" rms values, both to be minimized by selecting the damper B accurately for each of the 3 (three) different schemes of disturbances. After successfully applied to the standard double-integrator plant given as an illustrative example, the similar approach is implemented for an armature-controlled dc motor speed-control design.**

Keywords—root mean square; rms; objective function; double-integrator, disturbance, dc motor

I. INTRODUCTION

Classical methods to determine a parameter in the control systems design have been developed for almost a hundred years [1] since the steam engine's governor was invented. The most common methods are derived analytically from the system's responses to a certain input. The time response of a system to a step-input is one of the most common ways to characterize the performance of a control system [2]. The frequency response is also commonly used such as in methods based on the Nyquist criteria [3], or other methods.

Those methods based on the time response or the frequency response or both are usually valid and analytically verified, but in the field they - at least most of them - are not easily implemented due to a couple of reasons, among others for instance: (1) the methods require the use of sophisticated equipment such as an oscilloscope with the capability of displaying one-shot signals or a spectrum-analyzer for the frequency response, (2) the inputs should be a certain kind that is not easy to generate (an "ideal" step-function or an impulse-function $\delta(t)$ never actually exists), (3) even if the specific inputs may be approximated for some cases, they are not always applicable, for example: a step input of armature voltage cannot be actually applied to a large DC motor.

Measuring equipments - particularly used in electrical engineering - mostly display the measurement results in rms values - also called "effective" values - especially when the signal being measured varies with time considerably [4]. Other physical units are usually converted into electrical quantities using some sensors, and then their rms values are measured.

II. THE BASIC CONCEPT

A well established case of control design in the classical control theory is an unstable double-integrator plant representing a spring-mass-damper system with a mass **M** connected to a reference wall by a spring with the constant **K** stabilized by a damper with the constant **B** as represented by the block-diagram shown in Fig. 1.

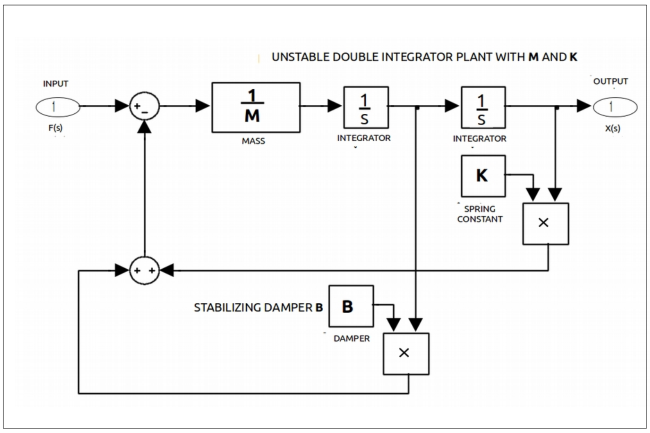

Fig. 1 An unstable double-integrator plant with a mass **M** and a spring constant **K**, stabilized by a damper B

The most common time-response is characterized by a step input. For a large **B**, the response is over-damped, which is characterized as too slow, while for a small **B**, the response is under-damped, characterized as too oscillatory. The "best" (both fast and non-oscillatory) performance is believed to be attained by setting the damping ratio $\xi = 1$, or:

$$\mathbf{B} = 2\sqrt{\mathbf{MK}} \quad (1)$$

The response for ξ = 1 is also characterized as critically damped response. A "normalized" plant with **M** = 1 unit mass and **K** = 1 unit spring constant requires **B = 2** units of damping constant to exhibit a critically damped response to a step input, as shown Fig. 2.

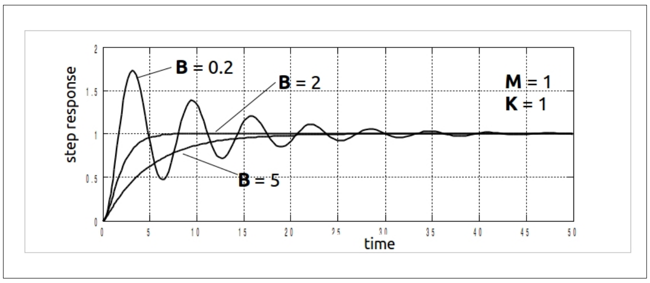

Fig. 2 The step-responses for **B** = 2 (*critically damped*), for **B** = 5 (*over-damped*) and for **B** = 0.2 (*under-damped*)

A. Arbitrary Disturbance and the Objective Function

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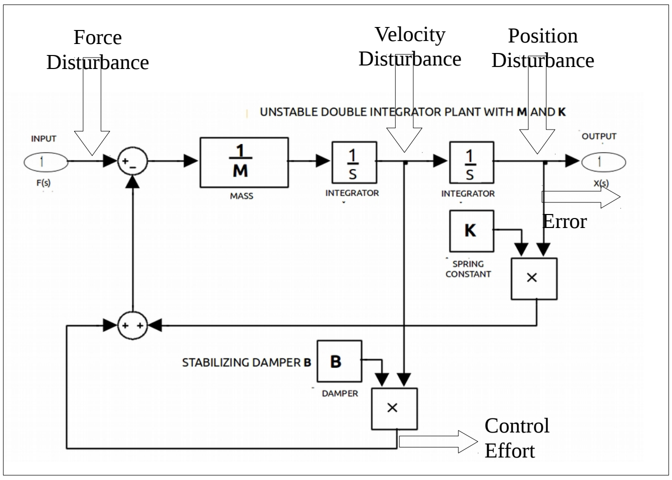

Fig. 3 Force, Velocity and Position Disturbances, Error and Control Effort

B. Optimizing the Spring Constant **B**

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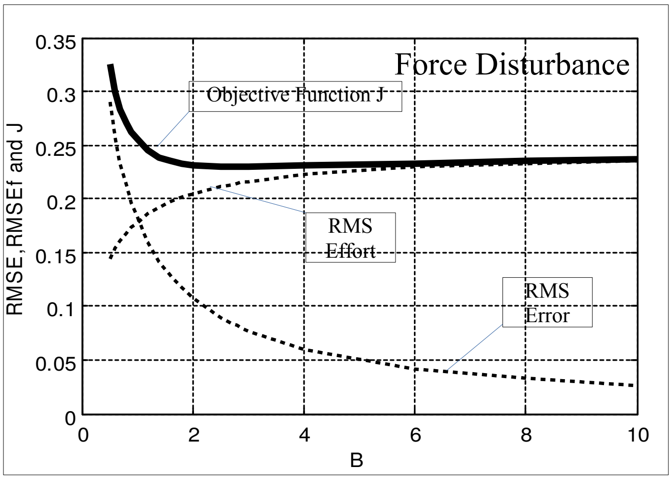

Fig. 4 The Error, Control Effort and the Objective Function of the Force Disturbance for Various Constant Spring B

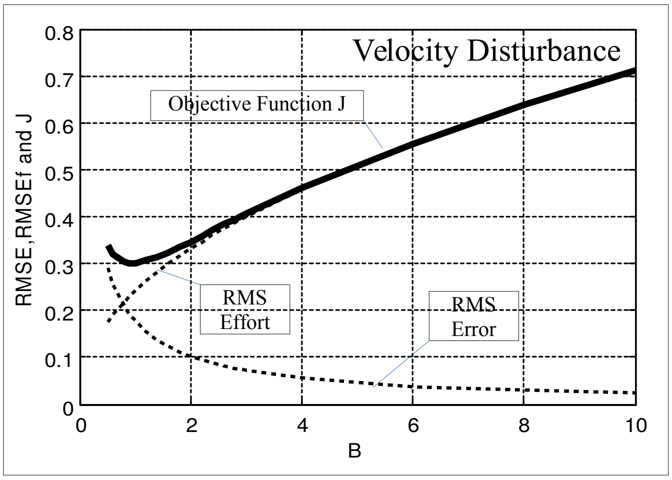

Fig. 5 The Error, Control Effort and the Objective Function of the Ve;ocity Disturbance for Various Constant Spring B

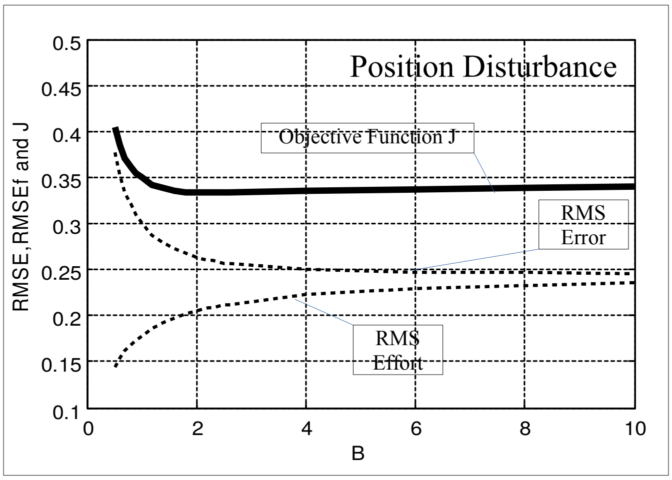

Fig. 6 The Error, Control Effort and the Objective Function of the Position Disturbance for Various Constant Spring B

Table 1 The Range of Minimizing B and the Damping Ratio ξ for each Type of Disturbance

Disturbance Type	Range of Minimizing B	Minimizing ξ (by curve fitting)	Characteristics
Force	2.7 - 2.9	1.4151	overdamped
Velocity	0.8 - 1.0	0.4734	underdamped
Position	2.4 - 2.6	1.2387	overdamped

III. THE PRACTICAL IMPLEMENTATION

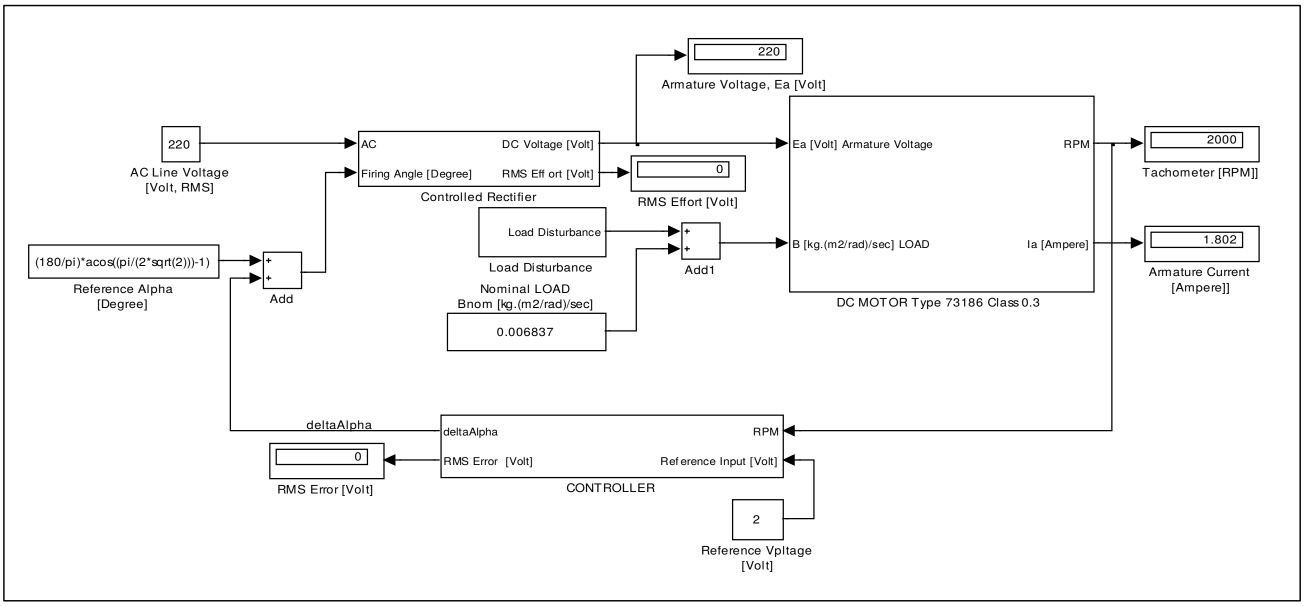

Fig. 7 An Armature Control DC Motor Speed Control Experimental Scheme

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$$a + b = \gamma \qquad (1)$$

$$\alpha + \beta = \chi. \qquad (1)$$

(1)

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	Table column subhead	***Subhead***	***Subhead***
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a. Sample of a Table footnote. *(Table footnote)*

b.

Fig. 1. Example of a figure caption. *(figure caption)*

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References

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[4] K. Elissa, "Title of paper if known," unpublished.

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