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

Rhiza S. Sadjad
Department of Electrical Engineering
Faculty of Engineering, Hasanuddin University
Makassar, South Sulawesi 90245 INDONESIA
e-mail: rhiza@unhas.ac.id URL: http://www.unhas.ac.id/rhiza/

***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 in this paper 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 4 (four) 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. An Illustrative Example

A well established case of control design in the classical control theory is an unstable double-integrator plant 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.

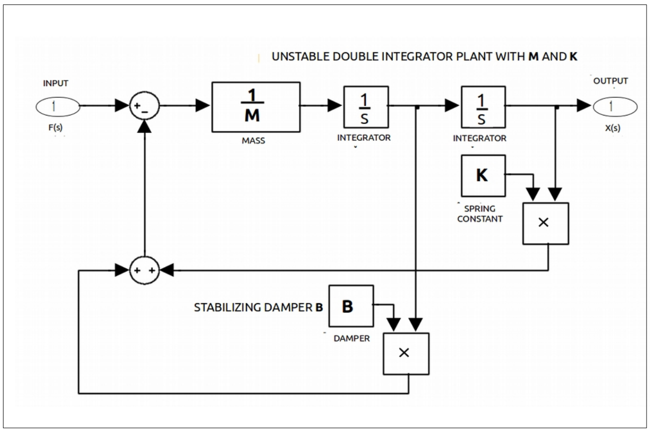

Fig. 1 An unstable double-integrator plant with a mass **M** and a spring constant **K**, stabilized by a damper B

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** to exhibit a critically damped response to a step input, as shown Fig. 2.

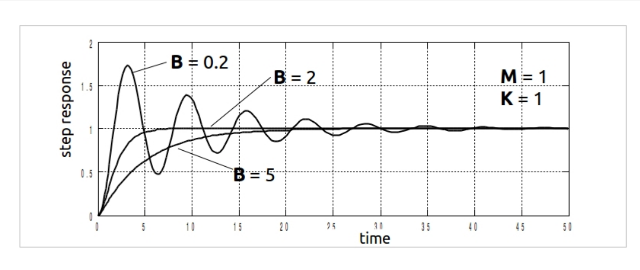

Fig. 2 The step-responses for **B** = 2 (*critically damped*), for **B** = 5 (*over-damped*) and for **B** = 0.2 (*under-damped*)

A. *Arbitrary Disturbance and the Objective Function*

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Define abbreviations and acronyms the first time they are used in the text, even after they have been defined in the abstract. Abbreviations such as IEEE, SI, MKS, CGS, sc, dc, and rms do not have to be defined. Do not use abbreviations in the title or heads unless they are unavoidable.

B. *Units*

- Use either SI (MKS) or CGS as primary units. (SI units are encouraged.) English units may be used as secondary units (in parentheses). An exception would be the use of English units as identifiers in trade, such as “3.5-inch disk drive.”
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$$a + b = \gamma \qquad (1)$$

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

(1)

Note that the equation is centered using a center tab stop. Be sure that the symbols in your equation have been defined before or immediately following the equation. Use “(1),” not “Eq. (1)” or “equation (1),” except at the beginning of a sentence: “Equation (1) is ...”

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- The word “data” is plural, not singular.
- The subscript for the permeability of vacuum μ_0, and other common scientific constants, is zero with subscript formatting, not a lowercase letter “o.”
- In American English, commas, semi-/colons, periods, question and exclamation marks are located within quotation marks only when a complete thought or name is cited, such as a title or full quotation. When quotation marks are used, instead of a bold or italic typeface, to highlight a word or phrase, punctuation should appear outside of the quotation marks. A

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c) Highlight author and affiliation lines of affiliation 1 and copy this selection.

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Component heads identify the different components of your paper and are not topically subordinate to each other. Examples include ACKNOWLEDGMENTS and REFERENCES, and for these, the correct style to use is "Heading 5." Use "figure caption" for your Figure captions, and "table head" for your table title. Run-in heads, such as "Abstract," will require you to apply a style (in this case, italic) in addition to the style provided by the drop down menu to differentiate the head from the text.

Text heads organize the topics on a relational, hierarchical basis. For example, the paper title is the primary text head because all subsequent material relates and elaborates on this one topic. If there are two or more sub-topics, the next level head (uppercase Roman numerals) should be used and, conversely, if there are not at least two sub-topics, then no subheads should be introduced. Styles named "Heading 1," "Heading 2," "Heading 3," and "Heading 4" are prescribed.

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1) Positioning Figures and Tables: Place figures and tables at the top and bottom of columns. Avoid placing them in the middle of columns. Large figures and tables may span across both columns. Figure captions should be below the figures; table heads should appear above the tables. Insert figures and tables after they are cited in the text. Use the abbreviation "Fig. 1," even at the beginning of a sentence.

TABLE I. Table Styles

Table Head	Table Column Head		
	Table column subhead	***Subhead***	***Subhead***
copy	More table copy[a]		

a. Sample of a Table footnote. *(Table footnote)*

b.

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

Figure Labels: Use 8 point Times New Roman for Figure labels. Use words rather than symbols or abbreviations when writing Figure axis labels to avoid confusing the reader. As an example, write the quantity "Magnetization," or "Magnetization, M," not just "M." If including units in the label, present them within parentheses. Do not label axes only with units. In the example, write "Magnetization (A/m)" or "Magnetization (A (m(1)," not just "A/m." Do not label axes with a ratio of quantities and units. For example, write "Temperature (K)," not "Temperature/K."

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References

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For papers published in translation journals, please give the English citation first, followed by the original foreign-language citation [6].

[1] G. Eason, B. Noble, and I.N. Sneddon, "On certain integrals of Lipschitz-Hankel type involving products of Bessel functions," Phil. Trans. Roy. Soc. London, vol. A247, pp. 529-551, April 1955. (*references*)

[2] J. Clerk Maxwell, A Treatise on Electricity and Magnetism, 3rd ed., vol. 2. Oxford: Clarendon, 1892, pp.68-73.

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

[5] R. Nicole, "Title of paper with only first word capitalized," J. Name Stand. Abbrev., in press.

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