Volume 7
ISSUE 3/2009

Academic Journal of Manufacturing Engineering

EDITURA POLITEHNICA

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ACADEMIC JOURNAL OF MANUFACTURING ENGINEERING

VOLUME 7, ISSUE 3 / 2009

This issue is sponsored by
Romanian Ministry of Education, Research and Youth

ISSN: 1583-7904

EDITURA POLITEHNICA

UNCERTAINTY OF MANUFACTURING SIMULATION

László POKORÁDI[1]

ABSTRACT: During mathematical simulation of real manufacturing system we can meet any type and rate model uncertainty. Its reasons can be incognizance of modelers or data inaccuracy. So, classification of uncertainties, with respect to they sources, distinguishes between aleatory and epistemic ones. The aleatory uncertainty is an inherent data variation associated with the investigated system or the environment. Epistemic one is an uncertainty that is due to a lack of knowledge of quantities or processes of the system or the environment. Aleatory uncertainty is primarily associated with objectivity, but epistemic uncertainty may be comprised of substantial amounts of both objectivity and subjectivity. Aim of the paper is to show types of manufacturing simulation uncertainties and methods used to investigate them. And a linear interval analysis method of manufacturing parametric uncertainties will be demonstrated.
KEY WORDS: simulation, modelling, model uncertainty, system engineering.

1. INTRODUCTION

During mathematical simulation of a real technical (such as manufacturing) system we can meet any type and rate model uncertainty. Its reasons can be incognizance of modelers or data inaccuracy.

The model uncertainty has been subject to considerable attention in the recent literatures. The purposes of Aven's papers are to discuss and give guidance on issues, emphasizing and treatment of uncertainties in the production assurance analyses. They recommend the implementation of a Bayesian approach based on prediction intervals, with different characteristics dependent on the project phase (Hjortelanda & Aven & Østebrø, 2007)(Nilsen & Aven 2003). Oberkampf encouraged a dialog between the risk assessment, reliability engineering, and generalized information theory communities on the subject of uncertainty representation, aggregation, and propagation (Oberkampf et al., 2004). in another paper, Oberkampf demonstrated a new framework of the general phases of modeling and simulation by a system-level example: the flight of a rocket-boosted. aircraft-launched missile (Oberkampf et al. 2002). Muzzioli and Reynaerts showed the interval linear systems and clarified the link between interval linear systems and fuzzy linear systems (Muzzioli & Reynaerts, 2006).

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Möller and Beer discussed non-probabilistic uncertainty modeling is by means of interval modeling and fuzzy methods (Möller & Beer, 2007). Perincherry et al. proposed an approach to analyze uncertainties of large-scale systems.

This approach enables to represent the context depended nature of uncertainty (Perincherry et al., 1993). Tang provided a systematic analysis of common sources of uncertainty for Integrated Vehicle Health Management prognosis applications, and presented a suite of mathematically rigorous tools to address several important uncertainty sources for prognostic uncertainty management and reduction (Tang et al., 2009). Ferson and Tucker shown the relationship between Probability Bounds Analysis — PHA and the methods of interval analysis and probabilistic uncertainty analysis from which it is jointly derived, and indicated how the method can be used to assess the quality of probabilistic models such as those developed in Monte Carlo simulations for risk analyses. They also illustrated how a sensitivity analysis can be conducted within a PBA by pinching inputs to precise distributions or real values. (Ferson & Tucker, 2006a)(Ferson & Tucker, 2006b).

De Chiffre gives a short overview of the role of geometrical metrology in modem manufacturing with focus on the industrial situation in Europe (De Chiffre, 2007).

The author applied interval and Probability Bounds Analysis methods to investigate effects of manufacturing parameter uncertainties

(Pokorádi, 2005). The author also used second-order probability uncertainty investigation method and worked up a new two-dimensional probabilistic maintenance estimation method theoretically, and shown possibility of use and experiments of first application of developed method (Pokorádi. 2007).

The paper gives a short overview of the types and sources of model uncertainties and illustrates model uncertainty examination methods by literatures mentioned above.

The paper will be organized as follows: Section 1 shows the applied literatures. Section 2 words the types of model uncertainties. Section 3 presents sources of uncertainties. Section 4 shows the investigation methods of parametrical uncertainties. Section 5 illustrates methodology of linear interval analysis method's usage to investigate effects of manufacturing parameter uncertainties.

2. TYPES OF UNCERTAINTIES

The mathematical model is the mathematical equation or system of equations which describes the internal principles of the process occurring on the system from the point of view of the given investigation (Pokorádi. 2008). On the one hand the real technical systems are precise, but complex. Additionally the large-scale systems consist of large number of inter-related subsystems. On the other hand, the mathematical model should be simple therefore may be imprecise. Mathematical modeling and simulation of complex technical systems must include the nondeterministic features of the modeled system and its environment or human interaction with the system (Perincherry et al., 1993). These nondeterministic features mean that the response of the system cannot be predicted precisely because of the existence of uncertainty in the system or the environment (Oberkampf et al., 2002).

One of the most widely recognized distinctions in uncertainty types is between aleatory and epistemic ones.

Aleatory uncertainty is an inherent variation associated with the investigated system or its environment. It is also called as variability, irreducible, random uncertainty or (in the control theory) parametric uncertainty. Aleatory uncertainty is primarily associated with objectivity.

Epistemic uncertainty derives from some level of ignorance of the physical process, the system or the environment. Experts use the term epistemic uncertainty to describe any lack of knowledge or information in any phase of the modeling and model application. This type of uncertainty may be comprised of substantial amounts of both objectivity and subjectivity.

3. SOUCES OF UNCERTAINTIES

Some of the types of uncertainty sources that can occur in modeling and simulation of technical systems include:

- false knowledge of system or its environment;
- incorrect application of scientific laws;
- selecting the appropriate model formulation;
- model generalization;
- model reduction;
- linearization;
- incorrect measuring;
- measuring noises;
- discretization;
- strong statistical information;
- sparse statistical information;
- using of linguistic data;
- selecting the appropriate database;
- manufacturing anomalies.

From point of view of epistemic uncertainty, we should know planed application of the model. The applicable model should be the most similar, but it have to depict the process from all important points of view of investigation with adequate accuracy. During generalization, reduction and linearization we can loss the model particularity.

To decrease epistemic uncertainties we have to have correct information about process taken in the investigated system. One of the most dangerous uncertainty sources when the modeler does not observe important process or material features. For example, we take fluid that an incompressible or frictionless one in case a hydrodynamic process investigation.

The most important source of parametric uncertainties is the measuring of system parameters. A complete statement of the result of a measurement of general parameter η must include information about the uncertainty of measurement ϑ at some probability level:

$$\eta_{real} = \eta_{meassured} \pm \vartheta \quad . \tag{1}$$

There are many factors influencing the measurement uncertainty: operator, environment and machine, workplace and measurement strategy. The most influencing Factor is the instrument-man. Therefore, as De Chiffre written, the operator training is thus the key to decrease measuring uncertainty and the importance of education must be strongly emphasized (De Chiffre. 2007).

4. INVESTIGATION METHODS OF PARAMETRICAL UNCERTAINTY

In uncertainty analysis, a neighborhood of alternative assumptions is selected and the corresponding interval of inferences is identified. By Ferson and Tucker's papers, there are two disparate ways to effect such a study (Ferson & Tucker, 2006a)(Ferson & Tucker, 2006b).

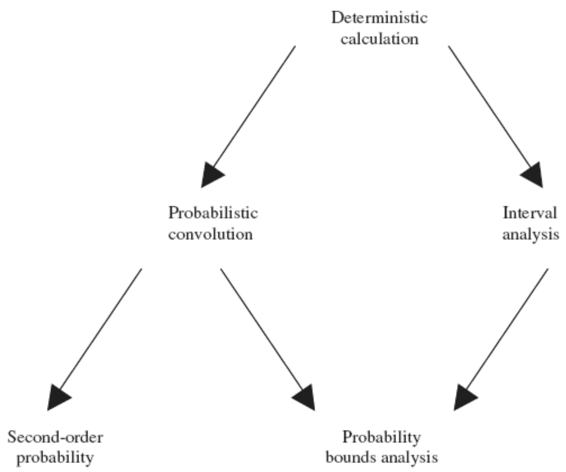

Figure 1. Relationships among Different Uncertainty Investigation Methods (Ferson & Tucker, 2006a)

One of them is the interval analysis (see Fig. 1.). The linear system

$$\mathbf{Ax} = \mathbf{B} \tag{2}$$

where elements a_{ij}, of the matrix $\mathbf{A}$ and the elements, b_i of the vector $\mathbf{b}$ are intervals, is called an interval linear system. The linear system, where the elements, a_{ij} of the matrix $\mathbf{A}$, and the elements, b_i of the vector $\mathbf{b}$ are fuzzy numbers, is called a fuzzy linear system. In case of particular type of linear systems elements of coefficient matrix $\mathbf{A}$ are crisp ones, while $\mathbf{x}$ and $\mathbf{b}$ are interval vectors.

The author used similar linear interval analysis method to investigate effects of manufacturing anomalies (see Section 5.). Using the proposed inverse methods, allowable uncertainties (in other words allowable manufacturing tolerances) of internal parameters can be determined on the basis the admissible uncertainties (required tolerances) of external system parameters. It is very important to mention that these data have to he investigated from the technological and the manufacturing points of view. If the technological possibilities do not meet the required quality, on the basis of the practicable tolerance zones of the internal parameters should be determined and the base investigation should be performed once more while the external system parameters will meet the requirements. It is also important to mention that this method does not give the unambiguous solution of the above-mentioned technical problem because this investigation uses any estimation process. This method is “only” an effective adjuvancy to determine the most practicable manufacturing tolerances of the internal parameters during the design of the system or its manufacturing process.

Another „natural” uncertainty investigation method is to ascribe a probability distribution to the elements in the neighborhood. One of the most well-known probabilistic uncertainty investigation methods is the Monte Carlo simulation. The „classical” Monte Carlo simulation is used as an uncertainty analysis of a deterministic calculation because it yields a distribution describing the probability of alternative possible values about the nominal designed) point.

In the Figure 1 there are two possible paths are shown as right and left downward arrows.

The left one shows a probabilistic uncertainty analysis of a probabilistic calculation. The resulting analysis would he a second-order probabilistic assessment.

Basically this method was used to depict uncertainty of maintenance capacity estimation model in former work of the author (Pokorádi, 2007). The method, that supposed that stochastic parameters are independent ones and have normal distributions, estimates work expenditure of repair using a two-dimensional probability model. This method estimates the expectable values of failure number and work expenditure of repair by „the first probabilistic calculation”. The uncertainty of this estimation is characterized by one collective probability (by „the second probabilistic calculation”) not by multiplication of estimation's probabilities of expectable failure number and repair work expenditure.

Another derived method applies hounding arguments to the probabilistic calculation and arrive at interval versions of probability distributions. Ferson and Tucker call such calculations PBA – Probability Bounds Analysis (Ferson & Tucker, 2006a). This approach represents the uncertainty about a probability distribution by the set of cumulative distribution functions. PBA is an uncertainty analysis of a probabilistic calculation because it defines neighborhoods of probability distributions

The author applied a similar method to investigate manufacturing uncertainties' effects in case of normal distribution of inner system parameters supposing that they are independent random variables with normal distribution (Pokorádi, 2005)

5. LINEAR INTERVAL ANALYSIS OF MANUFACTURING PARAMETRIC UNCERTAINTIES

One of the practical appearances of parametrical uncertainties is the manufacturing anomaly (Pokorádi, 2008). During the design of new technical systems, their manufacturing tolerances (i.e. allowable system parameter uncertainties) should be determined basically by working requirements of the system and technological possibilities of the manufacturer.

Using linearized mathematical diagnostic model of the given system, the problems mentioned above can be investigated and solved.

Mathematical model of a technical system, which consists k aggregates, and has p independent (input and inner) system parameters, can be written in general case:

$$\begin{aligned} f_1(y_1;y_2;\ldots y_k) &= g_1(x_1;x_2;\ldots x_p) \\ f_2(y_1;y_2;\ldots y_k) &= g_2(x_1;x_2;\ldots x_p) \\ &\vdots \\ f_k(y_1;y_2;\ldots y_k) &= g_k(x_1;x_2;\ldots x_p) \end{aligned}$$

or in simpler way: (3)

$$f(\mathbf{y}) = g(\mathbf{x})$$

where elements, x_i of the vector $\mathbf{x}$ vector are independent (input and inner) system parameters and elements, y_i of the vector $\mathbf{y}$ vector are dependent (output) system parameters.

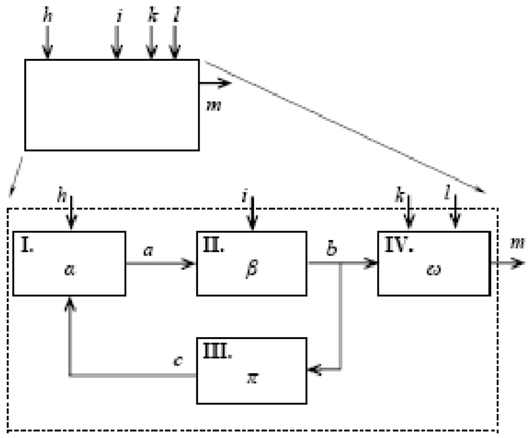

Figure 2. Block Diagram of Investigated System (Pokorádi, 2008)

For setting up linear diagnostic model, the mathematical model which is basically a non-linear system of equations should be linearized. For linearization, the logarithmic linearization method can be used.

The linear system of equations achieved in this way describes interdependencies between relative changes of independent ($\delta\mathbf{x}$) and dependent ($\delta\mathbf{x}$) parameters from the point of view of the given investigation. This model can be written in the following matrix formula:

$$\mathbf{A}\delta\mathbf{y} = \mathbf{B}\delta\mathbf{x} \ , \tag{4}$$

where $\mathbf{A}$ and $\mathbf{B}$ are coefficient matrices of external and internal parameters of the investigated system.

Using the

$$\mathbf{D} = \mathbf{A}^{-1}\mathbf{B} \tag{5}$$

diagnostic matrix, the equation

$$\delta\mathbf{y} = \mathbf{D}\delta\mathbf{x} \tag{6}$$

can be used for investigations that will be shown in the following chapters. This equation is the linearized diagnostic model of the given system.

To determine maximum and minimum values of external system parameters, as a first step, the vectors of relative maximum and minimum internal parameter values should be determined:

$$\delta\mathbf{x}_{\max} = (\mathbf{E}\mathbf{x}_{nom})^{-1}(\mathbf{x}_{\max} - \mathbf{x}_{nom}) \tag{7}$$

and

$$\delta\mathbf{x}_{\min} = (\mathbf{E}\mathbf{x}_{nom})^{-1}(\mathbf{x}_{\min} - \mathbf{x}_{nom}) \ . \tag{8}$$

5.1. The Investigation Method

In case of unknown distributions, the linearized diagnostic model — see equation (5) — of the investigated system should be modified. The so-called "positive diagnostic matrix" and "negative diagnostic matrix" should be introduced.

$$\mathbf{D}_{+} = \left[d_{ij+} = \begin{cases} d_{ij} & if \quad d_{ij} \geq 0 \\ 0 & if \quad d_{ij} < 0 \end{cases} \right] , \tag{9}$$

$$\mathbf{D}_{-} = \left[d_{ij-} = \begin{cases} d_{ij} & if \quad d_{ij} \leq 0 \\ 0 & if \quad d_{ij} > 0 \end{cases} \right] . \tag{10}$$

Knowing the above mentioned matrices, the vectors of relative maximum and minimum values of the external parameters:

$$\begin{bmatrix} \delta\mathbf{y}_{\max} \\ \delta\mathbf{y}_{\min} \end{bmatrix} = \begin{bmatrix} \mathbf{D}_{+} & \mathbf{D}_{-} \\ \mathbf{D}_{-} & \mathbf{D}_{+} \end{bmatrix} \begin{bmatrix} \delta\mathbf{x}_{\max} \\ \delta\mathbf{x}_{\min} \end{bmatrix} . \tag{11}$$

Knowing the relative maximum and minimum external parameter values can be determined.

5.2. The Inverse Method

If the task and work of the investigated (designed) system limits the output parameter values and their tolerances strictly, the manufacturing tolerances of internal parameters should be determined or estimated depend on required output parameter tolerances. This task can be solved by the inverse method of investigation mentioned above.

For estimation of required maximum and minimum values of internal parameters, firstly the relative maximum and minimum value vectors of output ones should be determined by following equations:

$$\delta\mathbf{y}_{\max} = (\mathbf{E}\mathbf{y}_{nom})^{-1}(\mathbf{y}_{\max} - \mathbf{y}_{nom}) \ , \tag{12}$$

and

$$\delta\mathbf{y}_{\min} = (\mathbf{E}\mathbf{y}_{nom})^{-1}(\mathbf{y}_{\min} - \mathbf{y}_{nom}) \ . \tag{13}$$

Then, the required maximum and minimum value vectors of internal parameters can be determined on basis of hyper-matrix equation (11). The vector which satisfies the scalar-vector equation

$$\left(\begin{bmatrix} \delta\mathbf{y}_{\max} \\ \delta\mathbf{y}_{\min} \end{bmatrix} - \begin{bmatrix} \mathbf{D}_{+} & \mathbf{D}_{-} \\ \mathbf{D}_{-} & \mathbf{D}_{+} \end{bmatrix} \begin{bmatrix} \delta\mathbf{x}_{\max} \\ \delta\mathbf{x}_{\min} \end{bmatrix} \right)^2 = 0 \tag{14}$$

should be estimated using any search of optimum method.

On the basis of vector estimated above, the required real (measurable) values of internal parameters can be determined.

It is very important to mention that these data have to be investigated from the technological and the manufacturing points of view. If the technological possibilities do not meet the required quality, on the basis of the practicable tolerance zones of the internal parameters should be determined and the base investigation should be performed once more while the external system parameters will meet the requirements.

It is also important to mention that this method does not give the unambiguous solution of the above-mentioned technical problem because this investigation uses any estimation process. This method is „only" an effective adjuvancy to determine the most practicable manufacturing tolerances of the internal parameters during the design of the system.

6. CLOSING REMARKS

The writer of this paper would like to arouse readers' interest in importance and possibilities of use of mathematical model uncertainty analysis. The paper has shown types of mathematical model uncertainties, their possible sources. The model uncertainty investigation methods also have been shown. Then a linear interval analysis method of manufacturing parametric uncertainties had been demonstrated.

During prospective scientific research related to this field of applied mathematics and technical system modeling, the author would like to work out methods to depict model uncertainty

- if uncertainties if inner system parameters are not independent stochastic variables and they do not have only normal distributions:
- using interval linear systems;
- using fuzzy set theory and fuzzy linear systems.

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