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Proposal of Design Method in the Semi-Acausal System Model

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Abstract**—**This study is used as a definition method to the value and function in manufacturing sector. In concurrence of discussion about present condition of modeling method, until now definition of 1D-CAE is ambiguity and not conceptual. Across all the physic fields, those methods are defined with the formulation of differential algebraic equation which only applied time derivation and simulation. At the same time, we propose semi-acausal modeling concept and differential algebraic equation method as a newly modeling method which the efficiency has been verified through the comparison of numerical analysis result between the semi-acausal modeling calculation and FEM theory calculation.

Keywords**—**System Model, Physical Models, Empirical Models, Conservation Law, Differential Algebraic Equation, Object-Oriented.

I. Introduction

IN manufacturing sector, CAE have contributed to the reduction of development time and improvement of reduction and product quality of development cost [1]. Compared to 3D-CAE that is defined configuration during designing, the practical implementation of 1D-CAE is retard. But in recent years, due to the advance international standardization of Modelica, the universal tools that easily develop, 1D-CAE system have become sold in market. However, during modeling the physical and experimental integrated model or the model that physical domain and mixture physical domain are deal together simultaneously, we find it is hard to indicate the physical phenomena [2].

Therefore, since the practical implementation and general spread is not as easy as the expectation, HLMD (High Level Model Description) and HLMT (High Level Model Tool) have been proposed as countermeasure.

Aiming the same objective that has been used in Modelica, this research sets up the approximate physical model alleviated with conservation law around the practical limit of semi-acausal model at existing physical model. By correcting the error in experimental model, we try to propose the numerical analysis method which can be able to construct a practical model. It found that so many ambiguities in the design information to make a conceptual design in a later stage of product design [3]. So, in addition of this research is to define the formulation of 1D-CAE without being conceptual and ambiguity, (1D-CAE is a formulation and simulation's method which only apply the derivation of time in differential algebraic equation across all physic fields).

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Thus, based on formulated definition of 1D-CAE above, noted that partial differentiation of spatial variable number is only as inauguration in the model which will be introduced when needed. As a typical example, modeling method nucleus of 1D-CAE in mechanical field is using spatial variable number widely in multi body dynamic. Fig. 1 shows the technical organization of 1D-CAE.

II. Present Condition of Modeling Method

A. Object Orientation

Object orientation is one of software development method, which brings a great contribution to the development of 1D-CAE and to the advance of technical use. Object orientation adopted the basic conceptual under 3 situations:

(1) Development of 1D-CAE software.
(2) Operation and utilization of 1D-CAE software.
(3) Construction method of a new model part and the whole system model made by user.

Using basic conceptual, the readability and reclamation of constructed model is found easier. Some important features of modern Object Orientation are [4]:

(1) Modeling of various kinds of physical systems with object oriented approach.
(2) Acausal model building.
(3) Symbolical and numerical solving of system of equations – algebraic formula manipulation.
(4) Algebraic loops solving.

B. Causal Model and Acausal Model

Until now, 1D-CAE format is classified broadly to causal model and acausal model.

1. Causal Modeling Format

Causal modeling format is a relationship between cause and effect in calculation order between model parts which are formed of 1D-CAE model. On the other hands, it shows the relationship between input and output, known and unknown quantity and also can be defined as a calculation order of the whole physical system.

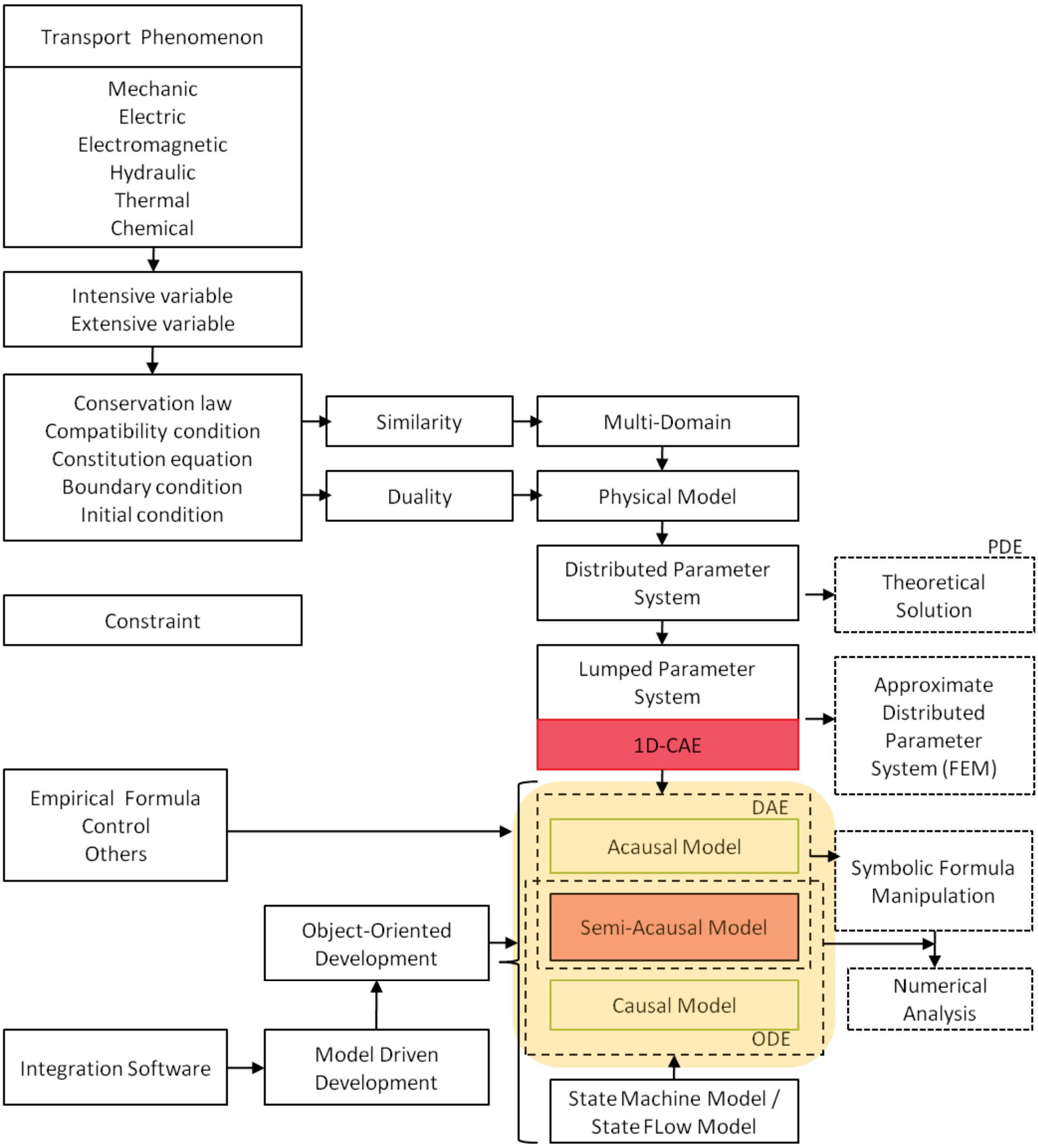

Fig. 1 Technical organization of 1D-CAE

Generally, it is not fixed in only each part of model, but it is fixed after all parts of model are topology formed. Causal model format is adopted in software represented by Simulink, Xcos and so forth. Before input the model, users usually finalize the calculation order, show it in block diagram and make it to simulation format. A significant effort in term of analysis and analytical transformations is needed to obtain a problem in this form. It requires a lot of engineering skills and manpower and it is error-prone [5].

2. Acausal Modeling Format

In order to allow the reuse of component models, the equations should be stated in neutral form without consideration of computational order. This is so called acausal modeling. Acausal modeling format leave the calculation order finalization to 1D-CAE software. Hence, before conducting numerical analysis, formula manipulation is used to change the differential algebraic equation group to ordinary differential equation (ODE) group before becoming able to carry out numerical analysis. In nature, real systems are acausal. For an example is, we never know whether in resistor current causes voltage or voltage causes current [5]. If we compare between causal model and acausal model, acausal model is easier to build and modify.

III. Modeling Method Difficulty and Proposal of Semi-Acausal

Even though acausal model calculation order have been through the automatization, there are some problems occur which cause disturb in its progress.

(1) The existing conditions that satisfied conservation law are not practical.
(2) The amendment of newly conservation law is difficult.
(3) The increment of newly concepts and terms are hard to general engineer.

In order to solve the problems, we propose semi-acausal modeling format. Semi-acausal modeling format is an imitation of acausal modeling format, which essential conditions are:

(1) Object orientation modeling use data flow block diagram.
(2) Modeling subject is algebraic derivative equation.
(3) Changes of data flow is easy where the junction correction terminate easily when unknown quantity in existing model is changed to known quantity.

Without relying on the automatization of calculation order, unlike acausal model, semi-acausal model use specific/peculiar block to imitate the JUNCTION block in Bond Graph then serve differential algebraic equation to carry out the numerical analysis. The specific block adopts the algebra loop refrain step that is used in causal model construction. It does not been used as an error refraining but is applied aggressively in numerical analysis method of differential algebraic equation.

The characteristics of semi-acausal model are:

(1) Fill the imperfection of acausal model where the establishment is possible under the extended of numerical analysis.
(2) Readability and reclamation can be ensured by following object orientation.
(3) There is a possibility of numerical analysis (repeating calculation) change into formula manipulation.
(4) Algebra loop scheme cause by try and error is not necessary. Construction of practical model is possible by setting up the approximate physical model that has been alleviated with conservation law around the existing physical model.

Through this setting, error in experimental model is corrected, and the construction of practical model is possible. However, there is concern that due to the repeating calculation, it takes much time to carry out this modeling method.

IV. Semi-Acausal Model Verification

In order to verify the efficiency of this newly proposed numerical analysis method, we give an example of springs with series and parallel connection and compare the integral of FEM theory and semi-acausal model. Fig. 2 shows the configuration of spring model, where the displacement x_1, x_2, and x_3 during outside load f_1, f_2, f_3 are applied at point of contact 1, 2, 3 are calculated. k_1, k_2, k_3 are spring constant while r_1 is reaction force. Displacement of joint 0 is zero.

System model analysis and FEM analysis outline procedure diagram is showed in Figs. 3 (a) and (b).

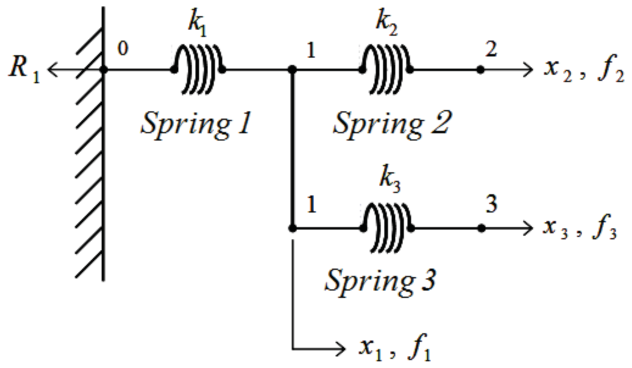

Fig. 2 Configuration of spring model

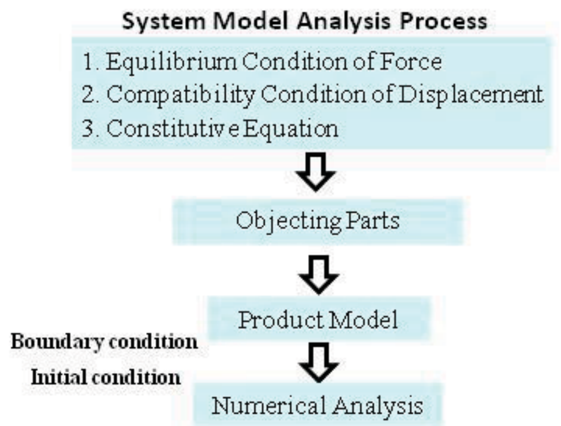

Fig. 3 (a) Outline procedure of system model analysis diagram

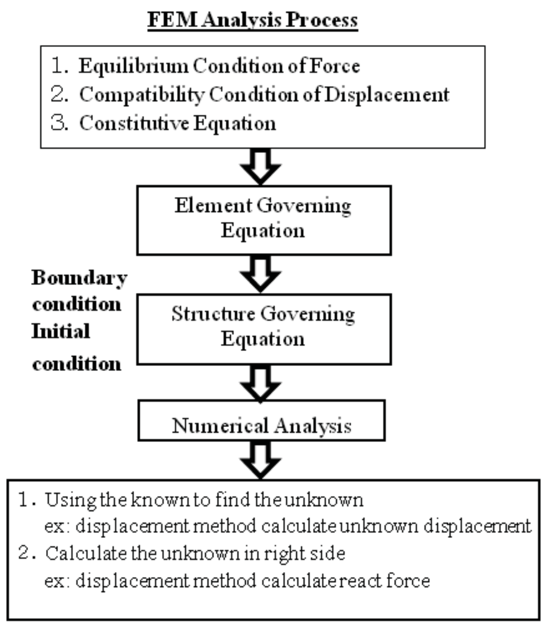

Fig. 3 (b) Outline procedure of FEM analysis diagram

A. FEM Theory

By using FEM theory, spring model in Fig. 2 can be indicated as (1):

$$\begin{bmatrix} k_1 & -k_1 & 0 & 0 \\ -k_1 & k_1+k_2+k_3 & -k_2 & -k_3 \\ 0 & k_2 & k_2 & 0 \\ 0 & -k_3 & 0 & k_3 \end{bmatrix} \begin{Bmatrix} x_0 \\ x_1 \\ x_2 \\ x_3 \end{Bmatrix} = \begin{Bmatrix} -R_1 \\ f_1 \\ f_2 \\ f_3 \end{Bmatrix} \quad (1)$$

Afterwards, by defining displacement in joint 0 as zero, it can be obtained for (2) as:

$$\begin{bmatrix} k_1+k_2+k_3 & -k_2 & -k_3 \\ k_2 & k_2 & 0 \\ -k_2 & 0 & k_2 \end{bmatrix} \begin{Bmatrix} x_1 \\ x_2 \\ x_3 \end{Bmatrix} = \begin{Bmatrix} f_1 \\ f_2 \\ f_3 \end{Bmatrix} \quad (2)$$

Here, when f_1, f_2, f_3 and k_1, k_2, k_3 are regarded as 1, displacement x_1, x_2, x_3 and reaction force R_1 values are showed as respectively

$$x_1 = 3, \quad x_2 = 4, \quad x_3 = 4, \quad R_1 = 3$$

B. Semi-Acausal Model

The newly proposed semi-acausal modeling method efficiency is verified. The boundary conditions of displacement x, reaction force R and elastic force F. Each in each spring in Fig. 2 is shown in Figs. 4(a)-(c).

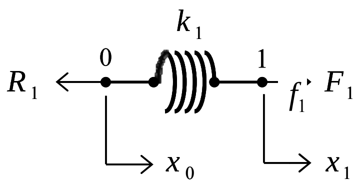

Fig. 4(a) Boundary condition of spring-1

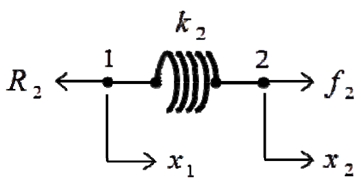

Fig. 4(b) Boundary condition of spring-2

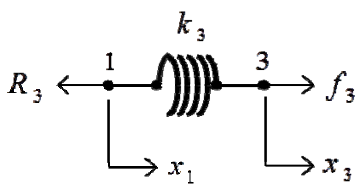

Fig. 4(c) Boundary condition of spring-3

Constitutive equation of spring 1 (Fig. 4(a)) is obtained as (3) and (4).

$$F_1 = k_1(x_1 - x_0) \quad (3)$$

$$R_1 = k_1(x_1 - x_0) \quad (4)$$

By considering the model readability, the known variable number x_0 is changed to unknown variable number. The equation is shown as in (5):

$$x_1 = x_0 + \frac{F_1}{k_1} \quad (5)$$

By modeling based on (4) and (5), Fig. 5(a) can be obtained. While modeling result of spring 2 and spring 3 are shown in Figs. 5(b) and (c) respectively.

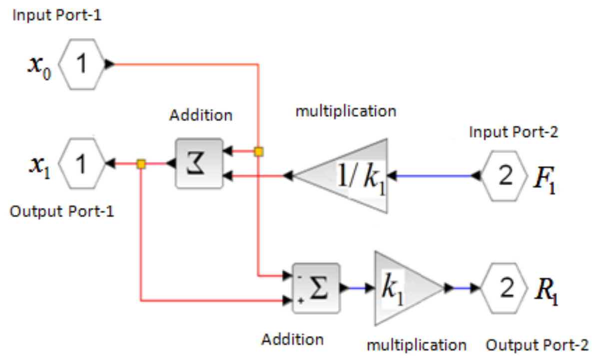

Fig. 5(a) Model diagram of spring-1

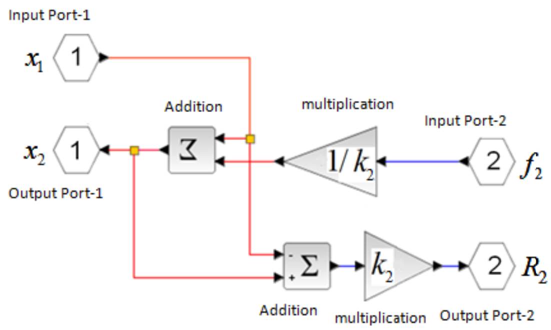

Fig. 5(b) Model diagram of spring-2

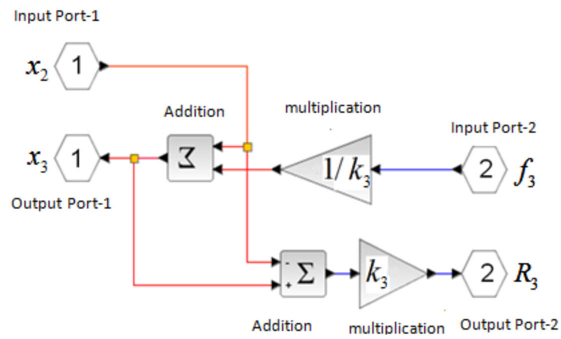

Fig. 5(c) Model diagram of spring-3

Next, the joint condition of joint 1 of each spring is considered, x_1 is common as compatibility condition in spring junction. Fig. 6 is obtained when modeling made based on this relation.

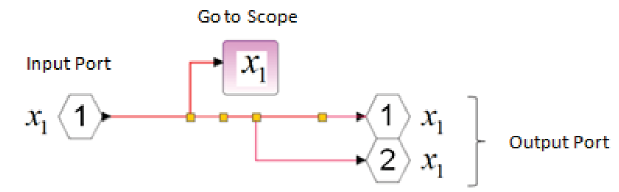

Fig. 6 Compatibility condition of displacement model

In addition, when considering about the equation of equilibrium, (6) is found valid. Due to modeling which is made based on (6), Fig. 7 is obtained. Since algebra loop is occurred in this model, it is essential to carry out convergence calculation.

$$f_1 + R_2 + R_3 - F_1 = 0 \quad (6)$$

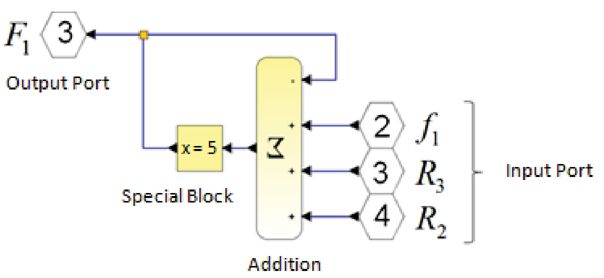

Fig. 7 Force equation of equilibrium model

Lastly, the whole spring model can be obtained by connecting all the input and output obtained in each of spring model and joint condition model that are determined before.

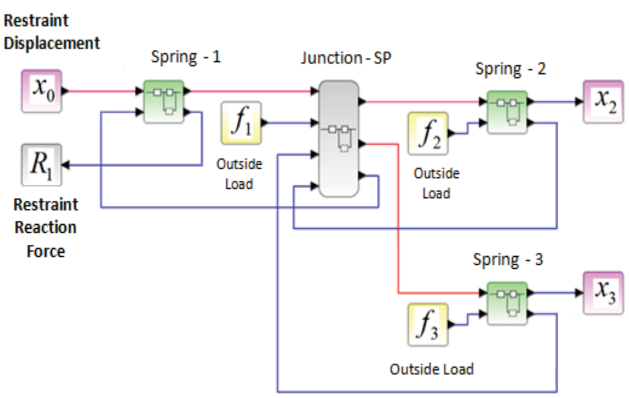

Fig. 8 Model diagram in semi-acausal modeling

Spring model in Fig. 8 is then calculated by using the general numerical analysis software that is called Scilab. The displacement x_1, x_2, x_3 and reaction force R_1 values is obtained respectively as:

$$x_1 = 3, \quad x_2 = 4, \quad x_3 = 4, \quad R_1 = 3$$

This result is exactly the same as the one calculated by FEM theory before when comparison is made.

IV. Conclusion

This study has fulfilled the imperfection of previous causal model and acausal model. Other than that, it promotes the proposal of semi-acausal model as a method which coexistence use is possible due to object orienting. Moreover, the efficiency of this modeling method has been verified throughout the comparison of numerical calculation result between FEM model and Scilab model which are corresponded to each other.

Yet, since the calculation example is still insufficient, in the future we hope to accumulate the verification, complete the semi-acausal modeling method and lastly aim to put it on practical implementation.

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