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Predicting mobile machine tool dynamics by experimental dynamic substructuring

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ABSTRACT

Predicting mobile machine tool dynamics prior to moving the machine to a new part and/or location is essential to guide first-time-right in situ machining solutions. This paper considers such a priori prediction of assembled dynamics under varying base/part/contact characteristics by applying dynamic substructuring procedures. Assembled dynamics are predicted by substructural coupling of the machine's known free-free response with the known response of any base/part measured at location. Since obtaining the machine's free-free response remains non-trivial, we instead extract the machine's dynamics using substructure decoupling procedures. Substructuring is carried out using measured frequency response functions. Methods are tested for robustness, and are experimentally validated.

1. Introduction

In situ machining, repair, and maintenance of large parts is made possible by moving mobile machine tools directly to the part locations. Moving the machine to the part results in significant savings in time, energy, and transportation costs that would otherwise be incurred from moving large parts to the machine's location [1,2]. An example of such a mobile machine tool developed at the Fraunhofer IWU [2,3] is shown in Fig. 1. The machine has a novel five-strut parallel kinematic configuration. A modular design allows it to be positioned at/on various parts and locations to facilitate in situ multi axis machining.

Despite its advantages, every new part and location that the machine is moved to results in different boundary conditions for the machine-part system. Varying kinematic configurations and base/part/contact characteristics significantly contribute to and influence machine dynamics. Changing dynamics interact with the cutting process and the control loop of the drives to influence and limit machining stability and accurate tracking and positioning of the tool. Since in situ machining solutions are essentially turn-key, there is a clear need for predicting the dynamics before moving the machine to the part location such as to guide selection of appropriate machining and control parameters that guarantee stable cutting and robust control.

This paper considers the experimental dynamic substructuring scheme that facilitates beforehand prediction of mobile machine tool dynamics under varying influences. Substructuring provides ways of obtaining the structural dynamics of large and/or complex structures by combining measurements and/or models of individual components/substructures for which the dynamic behavior is generally easier to determine. Substructuring hinges on being able to obtain the response of individual subsystems. Dynamics for an arbitrary part/base that the machine is moved to can be obtained by direct on site measurements. However, obtaining the machine's dynamics in its free-free configuration is non-trivial and needs special test rigs.

The main idea of this paper is to demonstrate the coupling of known dynamics of the mobile machine tool in its unsupported free-free configuration with measured dynamics of the base/part, measured separately at location for a priori prediction of the assembled system response. To obtain the machine's free-free response, we deploy substructure decoupling schemes to instead extract these dynamics from known dynamics of the mobile machine tool mounted on a calibration base, and from a priori information of the residual substructural base system. Extracted dynamics are subsequently coupled to another part/base model using the substructure coupling scheme. An overview of the proposed (de)coupling scheme is shown in Fig. 1.

Each substructural component can be represented by their spatial data, modal data, or their receptances, i.e. frequency response functions (FRFs). Spatial and modal representations form part of the family of the generalized component mode synthesis approach [4], and have been used previously in the design and analysis of machine tool concepts [5,6]. In the present case, the

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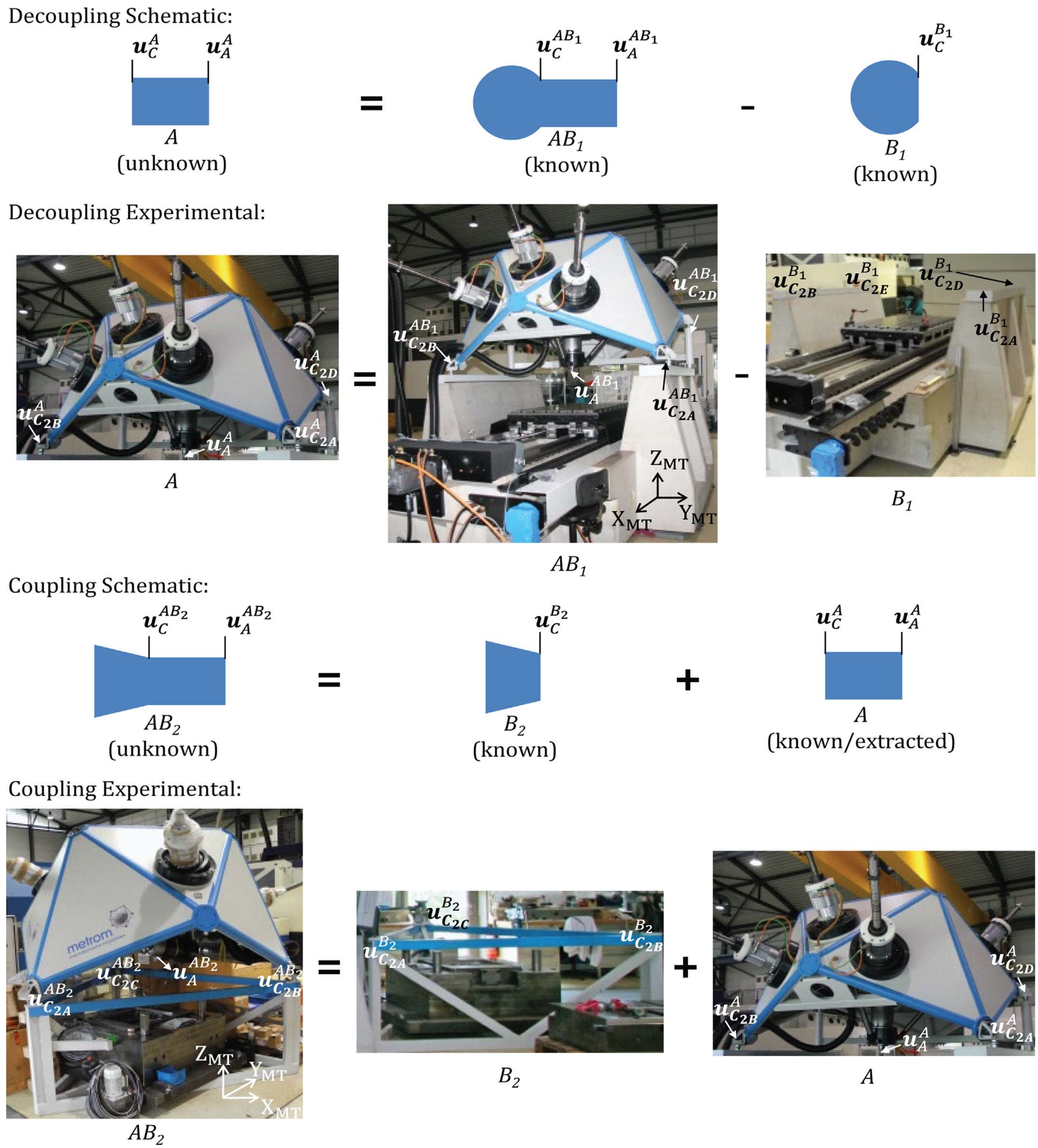

Fig. 1. Substructure decoupling and coupling schematic. AB_1 – mobile machine coupled to the first base type; B_1 – first base type only; A – extracted mobile machine tool; B_2 – second base type; AB_2 – mobile machine coupled to the second base type.

frequency based substructuring (FBS) methods [7] that instead use measured and/or modeled FRFs to describe each subsystem are preferred. FBS methods afford us the advantage of synthesizing FRFs of parts/bases measured at location with the dynamics, i.e. FRFs of the mobile machine as desired. Moreover, since tool point dynamics characterized by FRFs are directly used in predicting stable cutting conditions [8,9], predicting the assembled system dynamics using FRFs extends the utility of the methods employed in this paper.

Special cases of the FBS methods referred to as the receptance coupling substructure analysis (RCSA) approach, have found much use in machine tool applications to predict tool point dynamics [8–11]. Earlier use of RCSA/FBS methods that reported on the simple case of substructures in end-to-end contact, e.g. tool and tool-holder connections were subsequently extended in recent works for modeling complete machine tool substructures simultaneously