Prediction of turning stability using receptance coupling

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Abstract

This paper presents an issue of machining stability prediction of dynamic "lathe – workpiece" system evaluated using receptance coupling method. Dynamic properties of the lathe components (the spindle and the tailstock) are assumed to be constant and can be determined experimentally based on the results of the impact test. Hence, the variable of the system "machine tool – holder – workpiece" is the machined part, which can be easily modelled analytically. The method of receptance coupling enables a synthesis of experimental (spindle, tailstock) and analytical (machined part) models, so impact testing of the entire system becomes unnecessary. The paper presents methodology of analytical and experimental models synthesis, evaluation of the stability lobes and experimental validation procedure involving both the determination of the dynamic properties of the system and cutting tests. In the summary the experimental verification results would be presented and discussed.

Keywords: turning, machining stability, stability lobes, receptance coupling

1. Introduction

Ensuring appropriate dimensional accuracy and surface quality of machined parts is only possible when the machining is carried out in stable cutting conditions i.e. where there is no chatter vibrations, affecting both machined surface and also premature tool and machine subassemblies wear [1,2]. Particularly challenging case is the machining of compliant machine parts, e.g. slender shafts turning

However, chatter vibrations may be avoided by proper selection of cutting parameters such as feed rate, cutting depth and the rotational speed (of the workpiece for turning or the tool for milling). The selection of these parameters can be carried out using the stability lobes presented as a border cutting depth at which chatter vibration develops as a function of rotational speed [2,3]. In order to calculate the stability lobes it is necessary to know the model of the cutting process (determined by cutting force coefficients for specific machining operation) and the dynamic properties of the machine tool – holder – workpiece system. These dynamic properties as frequency response function (FRF) can be determined in a number of methods: analytically, numerically (ex. Finite Element Method models) or experimentally (ex. impact testing).

Furthermore, for efficient modeling of complex mechanical systems, dynamics substructuring methods can be used. The main assumption of these methods is that complex assemblies can be decomposed into single simple subsystems and thus using the correspondent mathematical and physical relationships can be reassembled. Besides formulations based on theoretical models, there are also methods to use experimental models such as, among others, receptance coupling method [5,6,7,8]. This approach enables to synthetize separately evaluated FRFs of the machine tool components and the workpiece. The Dynamic properties of the machine tool components (for lathe: the spindle and the tailstock) can be considered to be constant during the machining and can be determined experimentally, or based on the FEM modelling. The workpiece can be modelled as a circular cross section beam and its dynamic properties could be determined analytically. Having transfer functions of all system components a synthesis using the method of receptance coupling can be carried out. The next step is the stability lobes determination which apart from 'machine tool – holder – workpiece' FRFs require experimentally determined cutting force coefficients. Performed calculations could be validated by applying selected machining parameters in cutting tests.

In this paper "lathe – workpiece" system would be considered.

2. Receptance coupling

In this section the procedure of determining the frequency response functions of the system components and the procedure for carrying out the receptance coupling are presented.

2.1. Workpiece

Workpiece is modelled as a free-free circular cross section Timoshenko beam. The beam is considered to be free, because the boundary conditions are applied to the system during its synthesis and arise from the spindle and the tailstock dynamical properties.

2.2. Spindle

Apart from determining the transfer function in x direction (orthogonal to the workpiece axis and cutting velocity direction) it is also necessary to identify rotational degrees of freedom (RDOF) Ref. [5,6] (Fig. 1) due to the fixture properties.

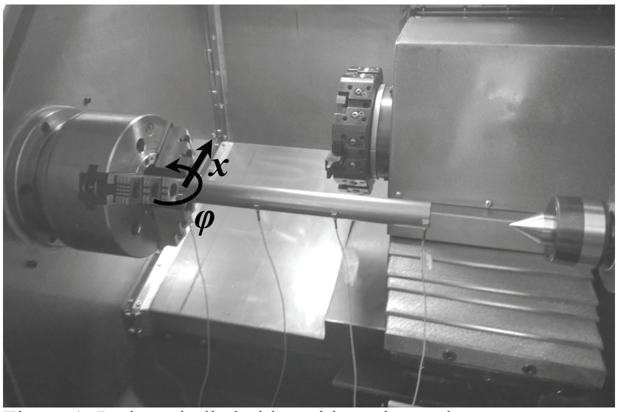

Figure 1: Lathe spindle holder with testing rod

However, the experimental measurement of an angular displacements by applying a moment and force is difficult [5,6,7,8] and therefore the dynamical properties of the spindle are determined using the authors method based on inverse receptance coupling. In the first step, in the considered lathe spindle chuck, a testing rod of known geometrical and material properties is mounted (Fig. 1). For such a coupled system the FRFs are experimentally determined by performing a series of impact tests. Then, the decomposition is being performed by subtracting the rod, analytically modelled as a beam, using inverse receptance coupling technique. As a result, the dynamic properties of the spindle are being evaluated.

2.3. Tailstock

The dynamics of the tailstock could be determined only as translational FRF at x direction, because the workpiece rotational motion in the supporting point is independent of the tailstock rotation. The FRF of the lathe tailstock is identified on the basis of the impact test results.

2.4. Receptance coupling

With all FRFs of the system components identified, the receptance coupling procedure can be performed. Imposing the boundary conditions and the equilibrium of forces between the components and the coupled system transfer function can be synthesised.

3. Stability lobes

Selection of proper machining parameters is carried out using the stability lobes, which apart from identified frequency response functions of machine tool – holder – workpiece, requires identification of the cutting forces coefficients. These coefficients are determined experimentally by measuring the cutting forces at specific machining parameters. Then, to evaluate the stability lobes, the method of simulation in time domain is used - for spindle rotational speeds, maximum cutting depth at which machining remains stable is being searched.

4. Experimental verification

In this section the experimental validation of proposed procedure is presented. In the first step the dynamical properties of the lathe spindle are determined using the authors inverse receptance coupling method. Then the impact test of the tailstock would be performed and FRF at the supporting point identified. The dynamical properties of the workpiece are calculated analytically by modelling as the circular cross section Timoshenko beam made of steel. On the basis of these results the transfer function of merged system is being synthesized using the receptance coupling method. Then, the workpiece would be mounted on the lathe, and the impact test of machine tool – holder – workpiece system would be carried out. The results of the transfer functions obtained experimentally would be compared with those previously synthesized. In the next step the machining test would be carried out. For this purpose, firstly the coefficients of the cutting forces would be determined experimentally, and on this basis, using the primary synthetized FRFs of the machine tool – holder – workpiece system, the stability lobes would be calculated. Finally, for selected sets of technological parameters (both for predicted stable and unstable conditions), the cutting tests would be carried out and the accuracy of the predictions would be reviewed.

5. Summary

In summary the experimental verification results, an opportunity for practical application of presented procedure and the direction of further researches are presented.

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