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A SPINDLE SYSTEM ANALYSIS USING SYSTEMS RECEPTANCE COUPLING APPROACH

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Abstract: The goal of this study is to dynamically simulate a turning-centre main spindle system utilizing the systems receptance coupling technique to determine the spindle system's first three resonant frequencies in the event of transverse vibrations. The findings are then confirmed using the finite element technique using ANSYS software. The significance of analysing the spindle system described in this study is that it can be utilized to optimize the spindle system in terms of resonance frequencies for improved performance in terms of spindle vibration while the turning centre is in operation.

Keywords: *dynamical analysis, turning centre, spindle system*

1. INTRODUCTION

Nowadays, it is essential to dynamically simulate machine tools systems. The objective is to increase the accuracy and productivity of these devices [1]. The basic goals of dynamical analysis are usually to monitor, analyse, and reduce mechanical vibrations in machine tools [2]. A mathematical model is often used to validate the model that is simulated using CAD 3D modelling and modal analysis [3]. The dynamical analysis and modelling of a CNC turning centre focus specific attention on defining the spindle's dynamical behaviour and the impacts of each component that is coupled to it [4]. Spindle models have recently been introduced to facilitate more precise dynamical evaluations, ranging from spindle models assume having rigid bearings [5] to models assume having flexible bearings [6] offering a much clearer view of the behaviour of this critical part of a turning-centre.

2. MATHEMATICAL MODELLING

For the spindle system considered, the main assumption is that the bearings are attached to a rigid frame, which implies that the rest of the machine structure is also quite rigid. The spindle's flexural (transverse) vibration will also be assumed to be in a single plane. The spindle may be broken down into several subsystems, such as shaft components and bearings, which can then be reassembled to form the entire spindle as illustrated in *Figure 1*.

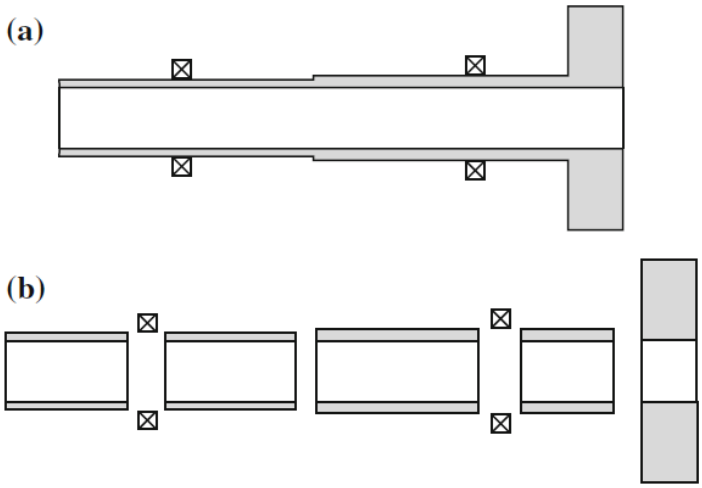

Figure 1. *Typical spindle (a), subsystem component (b)* [7]

Enforcing equilibrium and compatibility criteria at the joins is a part of the subsystem's addition process. There are two coupling connections between each subsystem because the connected ends of each subsystem's coupled ends must have compatible displacement and slope due to bending for the transverse bending vibration of shafts.

2.1. Receptance definition and systems addition

Receptances are used in systems approach, the receptance is defined as:

$$\alpha_{12} = \frac{X_1 e^{i\omega t}}{F_2 e^{i\omega t}} = \frac{X_1}{F_2} \tag{1}$$

where X_1 is the steady-state response of a system at the position and in the direction specified by the subscript 1 and is oftenly a complex number that indicates a phase with respect to the steady exciting force $F_2 e^{i\omega t}$ that is applied to the system at the position and in the direction specified by the subscript 2. The receptance of shafts including shear and rotary inertia effects were derived by Potter and Stone [8] and Stone [9]. Also, the receptance of bearings was derived taking into consideration their stiffness.

For adding systems, the process consists of breaking the combined system A into its component systems, or subsystems B and C, and applying forces to each subsystem at coordinate 1, causing the separate systems to behave exactly as they would when they were combined as illustrated in *Figure 2*.

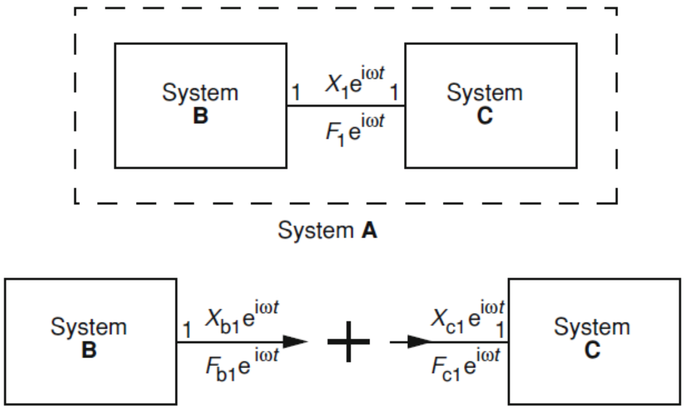

Figure 2. *The addition of two subsystems* [7]

3. The proposed model

After deriving the receptance of all the required components of a spindle system, the spindle system illustrated in *Figure 3* is analysed using systems receptance coupling approach. The shaft elements and the chuck are modelled as hollowed circular sections while the workpiece is modelled as a cylinder.

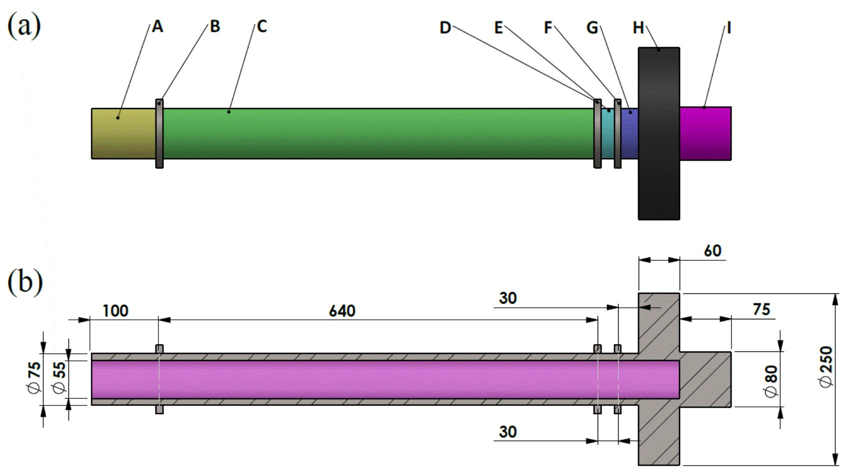

Figure 3. *The spindle system including the subsystems(a), the model dimensions(b)*

Figure 4 illustrates the block diagram of the spindle system including the shaft segments, the bearings, the chuck, and the workpiece. Symbols, D, F represent the bearings, H represents the chuck, Symbol I represents the workpiece and the rest of the subsystems represent the shaft segments. The used material of the spindle is assumed to be ASTM A36 steel. The stiffness of the bearing used in the analysis is 4.85 × 10^7 N/m [7].

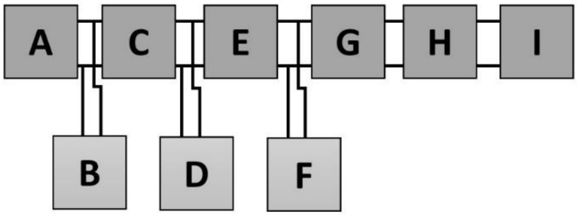

Figure 4. *Addition of shaft and bearing subsystems*

4. RESULTS

A code utilizing systems receptance coupling approach for analysing the spindle system presented in *Figure 3*. Is written to obtain the response of the system over a frequency range of 950 Hz as illustrated in *Figure 5*, the values of the first three resonant frequencies can be extracted and it can be observed that the relationship between the values of the resonant frequencies are not linear. The values of the resonant frequencies are listed in *Table 1*.

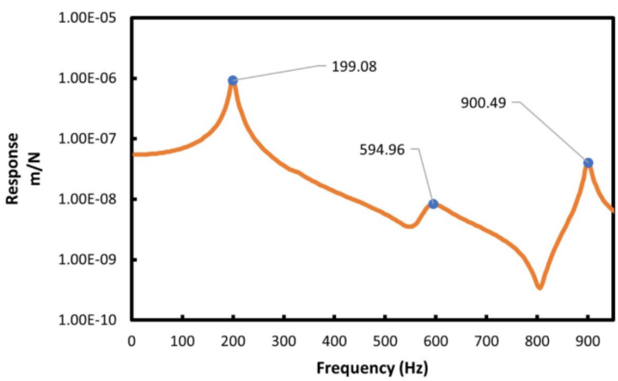

Figure 5. *Response of the proposed spindle system.*

Based on these results, resonance will take place in the spindle system when the excitation frequency meets one of the resonant frequencies listed in *Table 1*.

Table 1
Resonant frequency values

Mode number	Frequency Value [Hz]
1	199.08
2	594.96
3	900.49

Finite element modal analysis of the proposed model was performed using ANSYS V19 software to compare the results. *Table 2* lists the first three resonant frequency values.

Table 2

ANSYS resonant frequency results

Mode number	Frequency Value [Hz]
1	199.26
2	590.36
3	901

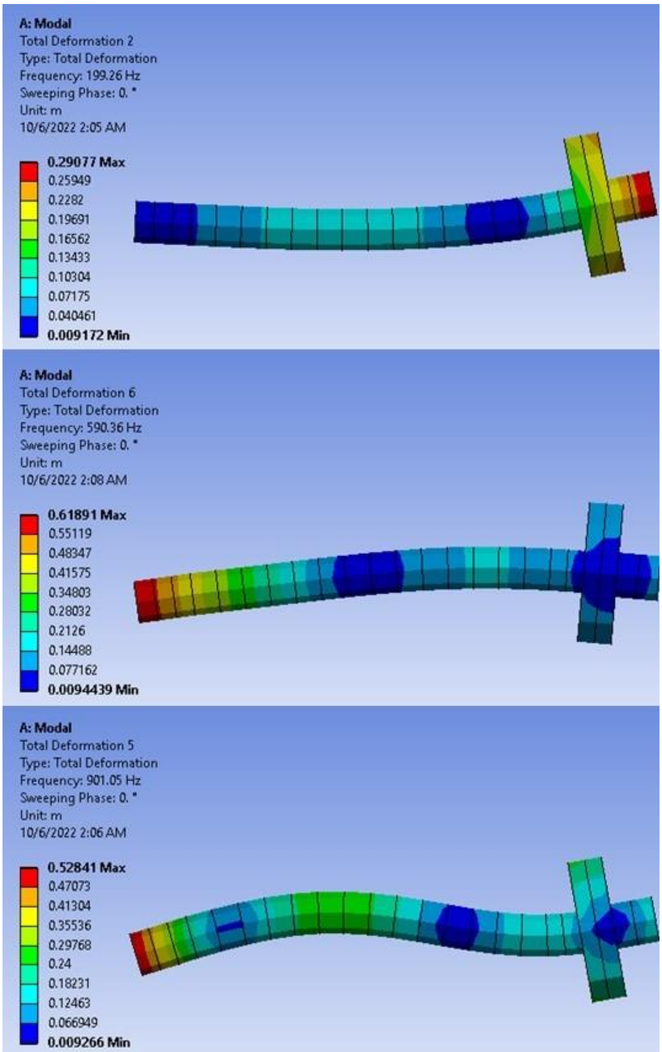

Figure 6. *ANSYS 19 spindle system mode shapes*

Figure 6 shows the first three resonant frequency mode shapes obtained from ANSYS 19. *Table 3* compares the results of first three resonant frequencies [Hz] of the spindle system using the systems receptance; coupling approach and the results from the finite element analysis using ANSYS software.

Table 3
Results comparison

Mode number	Receptance approach	ANSYS	Error %
1	199.08	199. 26	0.09%
2	594.96	590.36	0.78%
3	900.49	901.05	0.62%

5. Conclusions

A spindle system supported on three bearings is analysed using systems receptance coupling approach. The analysis takes into consideration the stiffness of the bearings. The main results are the first three resonant frequencies. The same spindle system is analysed using the finite element method using ANSYS software. The results of the two approaches then were compared. The comparison of the results shows a very good agreement in the values of the resonant frequencies.

The code written to analyse the spindle system suing the systems receptance coupling approach can be modified to take into account for different bearing stiffness (different kinds of bearings) values and location and different lengths and diameters of shaft segments, chuck and workpiece which can be helpful in the process of optimizing the spindle system in terms of resonant frequencies values.

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