**Ph.D SEMINAR - 1**

**Title:** Intelligent spindle with variable preload mechanism for machine tools to improve its limit of machining operability

**Date/Time:** 24th April 2025, Thursday, 11:00 AM-12:00 PM

**Venue:** Through Google Meet Link: meet.google.com/wtk-ahup-txs

**Speaker:** Mr. Anirban Tudu (ME17D021)

**Biography of the Speaker:**

Ph.D. Research Scholar (Manufacturing stream) in the Department of Mechanical Engineering

**Affiliation of the Speaker:** Research Guide: Dr. Sivasrinivasu Devadula, ME

DC Members: 1. Dr. Samuel G L, ME
2. Dr. Amitabha Ghosh, ME
3. Dr. Sujatha C, ME
4. Dr. Ramanathan M, ED

**Abstract**

Preload of the machine tool spindle bearing assembly needs to be controlled, according to the machining load, to change the spindle characteristics (*e.g.*, stiffness and heat generation). In general, preload is maintained low for low depth of cut and high-speed operations (*e.g.*, grinding, high-speed milling) to avoid high contact stress between the rolling elements and raceways that eliminates bearing seizure; whereas high preload is maintained for high depth of cut and low speed operations (*e.g.*, roughing, milling) with a heavy depth of cut to support the high cutting load. However, in the traditional spindle design, preload is applied during the assembly stage, and thus, spindles are constrained to a specific range of cutting parameters, hence not suitable for varying depth of cut in a wider range. Therefore, a variable preload mechanism achieved by introducing different actuators is being introduced to new-age spindles to have more control over the performance, which is one of the basic features of a smart spindle. The actuators linearly displace the bearing outer race and thus vary the preload. Though different actuators (*piezoelectric*, *electro-magnetic*, *hydraulic*, *pneumatic*) have been used, the cost, size and complexity of the mechanisms limit their application.

The present research aims to develop a framework towards developing an intelligent machine tool spindle with variable preload technology, with a hydraulic actuator in preload control due to their ease of design and cost effectiveness. The scope of the present work is i) to understand the spindle behaviour in terms of tool point frequency response function (FRF) and bearing temperature variations with respect to change in preload, ii) development of thermo-mechanical model of the spindle behaviours with respect to preload, iii) development of a spindle with variable preload

technology, iv) determination of optimum preload for specific cutting load, v) development of control algorithm for the variable preload, and vi) study the effect of preload in machining operation.

This *seminar 1* presents the experimental study of spindle behaviour with different preloads, modelling the spindle behaviour with respect to preload, and the development of a spindle with variable preload technology with a hydraulic actuator in preload control. Two spindle prototypes- identical designs with different preload levels (light and medium)- are developed, and their thermal behaviour under running conditions is studied. Results show that the spindle with light preload exhibits an increase in first mode frequency of the tool point FRF with increasing temperature, while the medium preloaded spindle demonstrates a reduction in the first mode frequency. These results align with the results in the literature on stiffness variation due to expansion and softening of bearing elements. Towards predicting the behaviour, a thermo-mechanical model of a spindle is developed, which can be used to determine the optimal preload for specific machining operations, considering the natural frequency and power loss from bearings. To evaluate the spindle performance in running condition, a calibration rod is designed, manufactured with the support of receptance coupling substructure analysis and multi-objective optimization approach to produce a smooth cylinder equivalent to a cutting tool. The calibration rod shows improved equivalency in the dynamic properties of the tool point FRF than a calibration rod designed with the conventional approach. Based on these studies, a spindle with variable preload technology with a hydraulic actuator is designed and manufactured. A proportional pressure control valve is introduced in the hydraulic circuit to control the preload with more precision. The spindle demonstrates a preload change with a precision of 10 µm, which aligns with the precision achieved in the literature. These elements contribute in realising and characterising an intelligent spindle in static and dynamic conditions.