Characterization of an LDC sensor and evaluation of cross-talk for the indirect measurement of the radial force on the tool of a Smart Spindle

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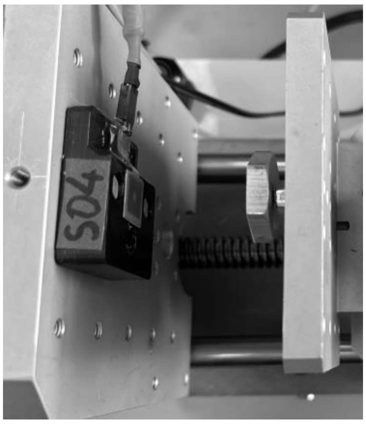
1. INTRODUCTION

Robot Machining is an emerging material removal technique in which, instead of using a conventional machine tool, an industrial robot is used, equipped with a spindle on its end-effector. The main challenges are the low stiffness of the manipulators that result in positioning errors, the process stability, and the accuracy of the milling tasks, compared to traditional machine tools [1], [2]. Also, a chatter reduction could help in extending the tool life. One method already known to improve performance in robotic machining is the introduction of a Smart Spindle. These devices are already known in the literature [3]–[5], and attempts have also already been made to indirectly measure cutting force [6], [7], however, the poor frequency bandwidth causes it to be still an open issue. In this paper, a different type of sensor that can be used for indirect measurement of cutting force on the tool correlated with the measurement of shaft bending is introduced and studied: the LDC inductive sensor. These sensors provide contactless inductive sensing of conductive objects using only an AC magnetic field and allow precise measurement of linear and angular position, motion, vibrations, and many other applications with high accuracy and reliability at a low cost. The first step necessary to implement this application is the study and characterization of this type of sensor.

2. MATERIALS AND METHODS

LDC sensors are composed of an inductor in parallel with a capacitor, to form an L-C tank oscillator.
When an AC flows through an inductor, it will generate an AC magnetic field. If a conductive material is brought into the vicinity of the inductor, the magnetic field will introduce an eddy current on the surface of the inductor, depending on the distance, size, and compensation of the conductor. The eddy current generates its magnetic field which opposes the original field, which is weakened. The change in the original field can be represented by a change in the inductance. The inductance and capacitance determine the resonant frequency of the sensor from the following equation: $f_{SENSOR}(Hz) = \frac{1}{2\pi\sqrt{LC}}$. Every change in the distance between the coil and the target material translates into a change in the inductance of the sensor. For the characterization of LDC sensors, a test bench has already been predisposed. The figure shows an enlargement of the fixed part, with a squared LDC sensor mounted on it, and the moving part, with a hexagonal aluminum target on it. The calibration bench consists of one side (i.e., the right side in the figure) of a carriage that can be moved by a worm screw, driven by a stepper motor, which transmission is sized in such a way to have a step size of about 100nm, on which the target material (i.e., aluminum), whose distance is to be measured, is placed. On the other side, the LDC sensor is fixed on a 3D-printed base which can be easily replaced. The sensor is connected to the *LDC1101* high-resolution inductance-to-digital converter from Texas Instruments, which makes it possible to perform inductance measurements with a sample rate greater than 180ksps and a resolution up to 24bit and can be easily connected to a microcontroller through a 4-pin SPI communication. The *NUCLEO-H743ZI2* board has been chosen, as it includes a high-performance microcontroller with a maximum clock



speed of 480MHz and DMA (i.e., Direct Memory Access) capabilities that allow to perform a high-speed transfer of data and make it possible to execute real-time OS directly on board (e.g., RTOS), a necessary feature for high-frequency acquisitions such as this one. This microcontroller is also optimized for the execution of AI algorithms directly on it. For the calibration of the LDC sensor, a position reference is needed. The *High-speed, High-accuracy Laser Displacement Sensor LK-G5000 Series*, with a repeatability of 0.005μm, will be mounted on the calibration bench for this purpose. The bench will be used to conduct multiple tests which will make it possible to best assess the coil geometry and number of turns best suited for the application. They will also make it possible to obtain a measure of the repeatability, stability, and long-term reliability of the sensor. Static calibration tests will be conducted, as well as tests to evaluate the variation in sensor behavior and accuracy as target and sensor curvature and coil geometry (e.g., square or circular) change. Subsequently, dynamic calibration will be carried out, as well as temperature characterization. Finally, the cross-talk between multiple sensors will be evaluated, as is noted that sensors with the same resonance frequency couple together.

3. CONCLUSION

In this paper, a new type of sensor suitable for indirect measurement of cutting force in a Smart Spindle for Robot Machining has been presented. Also, the test bench used for the characterization and calibration of the inductive LDC sensor has been presented, and the tests that will be carried out to evaluate the accuracy, repeatability, and cross-talk between multiple sensors have been described.

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