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A study on the feasibility of in-process compensation of cutting force induced errors using axes motors absorbed current.

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Abstract
Portable machine tools are developed to address specific applications needs, such as machining of large components. However, they lack in performance such as stiffness. For such a low-stiffness portable machine tool, in this work, it is analysed the possibility and feasibility of employing the motors absorbed current measurements during actual machining operations as a means to monitor the cutting process and eventually compensate the tool deformations due to the cutting forces. In-process tool-path compensation achieved through a sensorized machine is of extreme interest from the costs point of view, especially for portable or dedicated task machine tool. In this paper, measurements of cutting forces, feed axes and spindle motors absorbed currents were carried out simultaneously for different cutting conditions. It is found that good correlations can be established between specific feature of the cutting force and axis motors absorbed current, the result demonstrates that the absorbed current measurements are reliable indirect measurements of the cutting forces and can therefore be employed in an in-process tool-path compensation.

In-process compensation, Axes motors absorbed current

1. Introduction

Portable machine tools are designed to reduce costs and resources necessary to perform dedicated tasks, such as milling of large components like wind turbine parts. Such machines however, do not guarantee the same performance (e.g. stiffness, accuracy, thermal stability) as conventional machine tools. The specific study case deals with a portable machine tool, designed to machine wind turbine hubs, Figure 1 below.

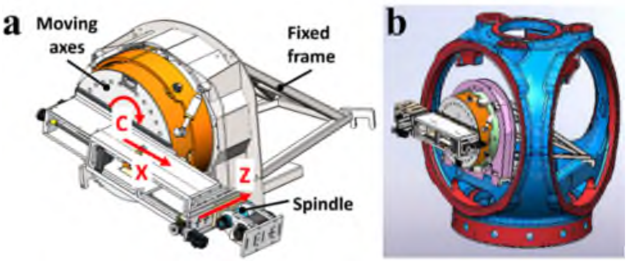

Figure 1. (a) Drawing of the machine composed of all its parts, the moving axis (indicated by the red arrow) and the supporting frame. (b) Visualization of the machine mounted on the hub in a typical working condition. Hub diameter is approximately 3 m.

An offline tool-path compensation strategy was previously implemented on this machine tool. The approach was based on a reliable prediction of the cutting forces tailored for the hub's cast iron type [1] and the characterization of the machine tool stiffness, through the definition of a stiffness map over the whole working volume. The in-process tool path compensation is the attempt to bring on a real-time level the offline tool-path compensation approach, developed by several authors [2,3], using integrated sensors into the machine, performing indirect measurements of the cutting force.

The measurement of axes and spindle motors absorbed current enables monitoring of cutting processes, as proved by several studies in the tool wear field [4]. For the present case study the use of the motor's absorbed current as an indirect measurement of the cutting forces to be used for the compensation of the cutting forces induced surface errors is analyzed. Machining tests at different cutting parameters were carried out. To compare different conditions a complete characterization of the motors absorbed current necessary for the machine movement only was carried out. The result of this characterization represents the baseline from which the contribution of the cutting forces to the absorbed current can be isolated and an appropriate comparison with the measured forces can be achieved.

2. Material and methods

The machine was used while mounted on the hub. A set of linear path climb milling tests were conducted to measure absorbed current and cutting forces, using small workpieces, made of the hub's cast iron, GJS 400 18U LT. The workpiece was attached to a dynamometer, which was bolted directly to the hub.

Table 1 Cutting parameters used in the machining tests.

Cutting Parameters	Values
Ae: radial engagement (mm)	16, 35
Ap: axial engagement (mm)	1.5
Feed per tooth (mm)	0.04, 0.08, 0.12, 0.18
Cutting Speed (m/min)	300

Cutting force measurements were carried out with a Kistler 9139A dynamometer at 10 kHz, while the motors absorbed current were measured via Siemens sensors TM31, linked to the machine PLC. The output signal is a 0-10 V signal proportional to the current. For the latter sensor the acquisition rate was limited

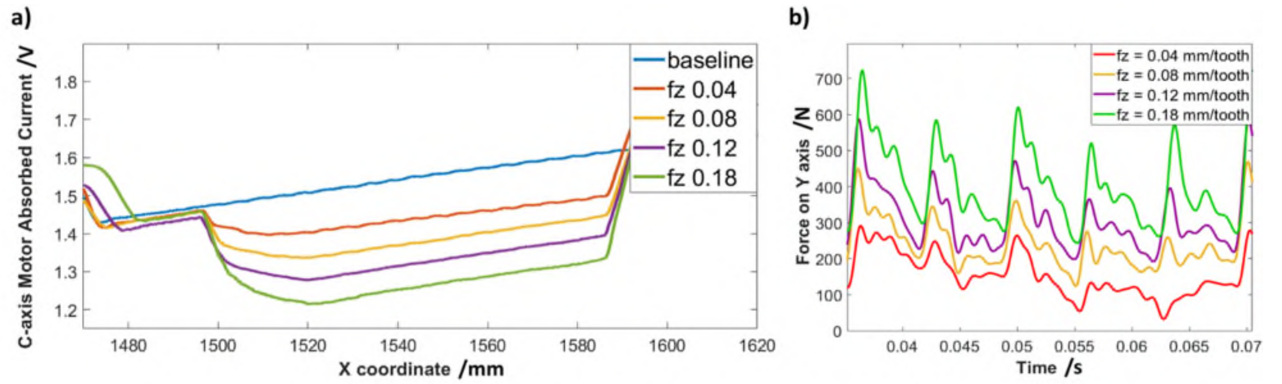

Figure 2. a) Measurement of absorbed current of C-axis motor as a function of the tool coordinate in the working space, for different values of feed rate and for Ae = 35 mm. The current signal is filtered with a moving average filter. b) Measurement of the cutting forces on the Y-axis (the axis orthogonal to X and Z in Figure 1) for the same machining tests. Only a single tool rotation is shown for clarity.

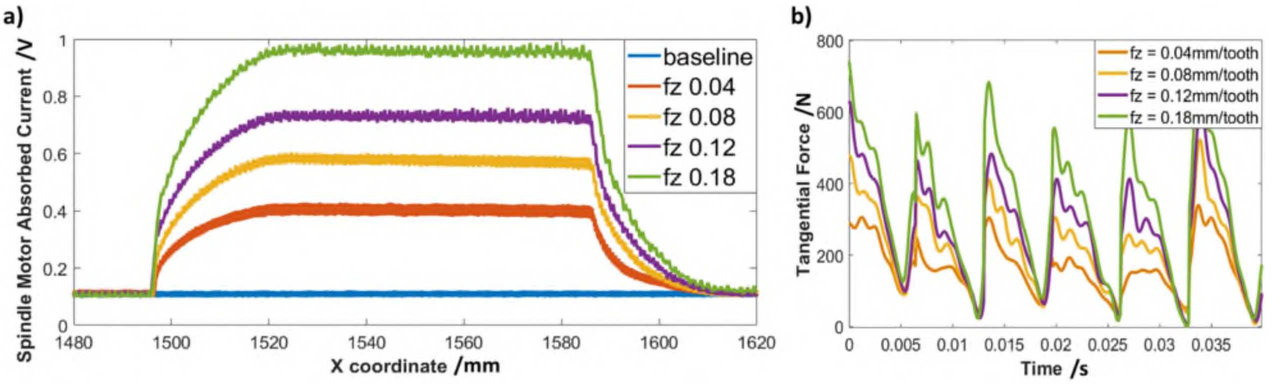

Figure 3. a) Measurement of absorbed current of the spindle motor as a function of the tool coordinate in the working space, for different values of feed rate and for Ae = 35 mm. The current signal is filtered with a moving average filter. b) Measurement of tangential forces on the cutting tool calculated from the measured cutting forces for the same machining tests. Only a single tool rotation is shown for clarity.

at 250 Hz. The cutting tool used was the Sandvik indexed tool R390-054Q22-17M, with TiAlN coated inserts. Table 1 reports the tested cutting parameters, full factorial approach, with three repetitions. For each test, measurements of the axes motors absorbed current related to the machine movement only were carried out. The tool-path was kept identical to the machining tests; also, in this case, three repetitions were conducted.

3. Results and discussion

Simultaneous measurements of the absorbed current of the C-axis motor, the spindle motor, and of the cutting forces on the analogous axes, respectively the force along the Y axis and the tangential force on the tool, are shown in Figure 2 and Figure 3. The acquisition rate of the current sensors was not sufficiently high to detect possible variations due to the cutting teeth. For both cases, for higher cutting forces higher values of absorbed current are registered. It has to be noted that the entire profile of the forces and of the absorbed current shift toward larger values for higher feed rates. Statistical analysis showed a significant correlation between the average cutting force, both along the Y-axis and the tangential direction, and the average of the difference of the absorbed current between each test case and the appropriate baseline. Pearson correlation values were respectively 0.97 and 0.99. Regarding the absorbed current of the X-axis motor, not shown, no significant relationship was found with respect to the average cutting force along the corresponding axis.

The above considerations are only valid if the cutting process is stable and stationary, in fact, dynamic effects when present can be detrimental to the force measurements, see Figure 2a.

4. Conclusion

This study verifies the feasibility of using the indirect measurement of the axes absorbed current to estimate the cutting force as the first step toward the implementation of an in-process tool-path compensation. It was verified that a relevant statistical correlation exists between the current measurements and characteristics of the cutting forces. The possibility of establishing a reliable connection of this type, characterizing the machine movement requirements in terms of current consumption, offers the opportunity to use the absorbed current monitoring performance to develop an in-process compensation of cutting force induced errors.

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