Thrust Force Control in Drilling Applying a Sensor-less Cutting Force Monitoring Method

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Abstract

This study focuses on thrust force control for drilling of composite materials. Composite materials are difficult to machine due to their unique characteristics. We consider thrust force control one solution to drill composite materials. This paper proposes thrust force control applying a sensor-less cutting force monitoring method.

1 Introduction

Composite materials are often applied to aircraft parts because of their desirable strength-to-weight characteristics. However, composite materials are difficult to machine due to the different physical properties of the materials used in the layers [1]. Some methods to machine composite materials have been proposed in terms of improvement of tool shapes and tool materials [2]. In addition to those approaches, cutting force control based on machining process monitoring is pretty important [3]. The purpose of this study is to propose thrust force control applying a sensor-less cutting force monitoring method, which is appropriate for practical use [4], and verify that it is applicable to drilling.

2 Design of Thrust Force Control System

2.1 Sensor-less Cutting Force Monitoring Method on Z-axis

Our research team has developed a sensor-less cutting force monitoring method, which can estimate cutting force without an external sensor by using information from the position encoder and current reference [4]. A block diagram of a sensor-less cutting force monitoring method applied to the z-axis is indicated in Fig.1. Thrust force F^{thrust} is estimated from the following equation.

$$\hat{F}^{thrust} = \frac{g^{thrust}}{s + g^{thrust}} (Kt_n I^{ref} - M_n s\dot{z}) - \hat{F}^{fric} - \hat{F}^{grac} \cdots\cdots\cdots\cdots\cdots\cdots (1),$$

where M is mass, Kt is thrust force coefficient, z is stage position, I^{ref} is current reference, g^{thrust} is cutting force observer cutoff frequency, F^{fric} is friction force, F^{grac} is gravity compensator's force, G is a gravity constant and (subscript)$_n$ is a nominal value. As shown in Eq. (1), our proposed method estimates thrust force using motor output and inertia force. In our study, friction force is determined on the basis of a simple friction model. Additionally, the gravity compensator's force must be taken into account on the z-axis.

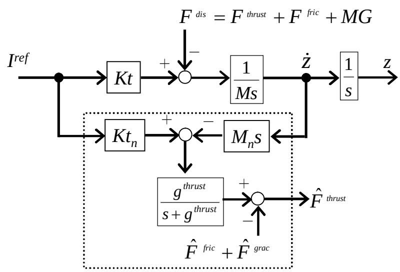
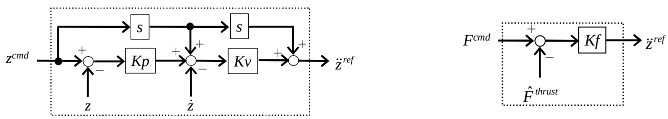


Figure 1: Cutting force observer

2.2 Design of Controller

The position controller and thrust force controller are designed and shown in Fig. 2 where Kp is position feedback gain, Kv is velocity feedback gain and Kf is force feedback gain. The position controller consists of PD control and feed-forward control and the force controller adopts P control. Both of them accomplish robust control by acceleration control with a disturbance compensator [4].



(a) Position controller (b) Thrust force controller

Figure 2: Design of controller

3 Simulation

3.1 Thrust Force Monitoring

To verify the validity of the cutting force observer to monitor thrust force, simulation was conducted, and then the estimated force $\hat{F}^{thrust}$ by cutting force observer and a force reference F^{ref} are compared. F^{ref} is defined as

$$F^{ref} = Kt_n I^{ref} - \hat{F}^{fric} - \hat{F}^{grac} \quad \text{(2)}.$$

Figure 3 indicates $\hat{F}^{thrust}$ is more accurately close to thrust force than F^{ref}. That means inertia force must be considered for precise estimation of thrust force.

3.2 Composite Material Drilling

The effect of thrust force on drilling of laminated composite materials was confirmed by simulation conforming to Table 1. F^{thrust} is given as direct proportion to feed rate $\dot{z}$ and K^{cut}. K^{cut} is configured properly to represent transitions of layers. Figure 4 explains that thrust force F^{thrust} follows command force by changing feed rate even if the layer of composite materials changes at (A) or (B).

Table 1: Simulation parameters

Kt_n	24.0 N/A
g^{thrust}	1200 rad/s

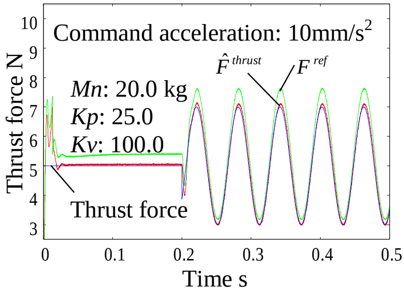


Figure 3: Thrust force monitoring

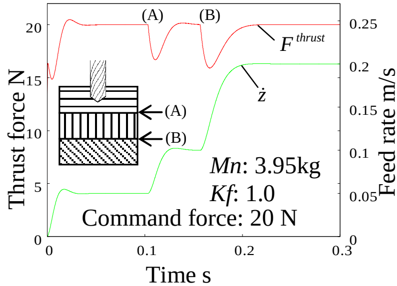


Figure 4: Composite material drilling

4 Experiment

4.1 Experimental Procedure

To evaluate the performance of our proposed control, aluminum drilling tests were carried out using the developed z-axis linear motor driven stage shown in Fig. 5. The stage includes a linear motor, two LM guides and a linear encoder (resolution: 4nm). Each control sampling time is set at 100 µs.

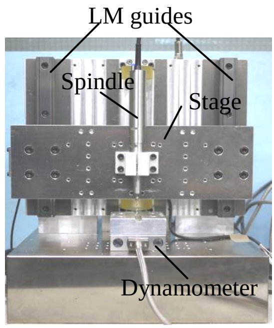


Figure 5: z-axis stage

4.2 Thrust force monitoring

Figure 6 shows the results of thrust force measured by our proposed method and dynamometer (Kistler Type9256C1) through a drilling test and its parameters of control are listed in Table 2. Our proposed method is effective for monitoring thrust force since estimated thrust force almost equates to the dynamometer's output.

Table 2: Experiment parameters

M_n	3.95 kg
Kt_n	24.0 N/A
Kp	25.0
Kv	100.0
Kf	0.45
g^{thrust}	1200 rad/s

4.3 Thrust force control

A thrust force control test was carried out. Figure 7 indicates that the average thrust force traces command force perfectly and the peak value of thrust force stays within a 5N error against command force.

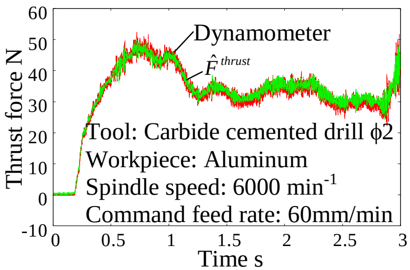


Figure 6: Thrust force estimation

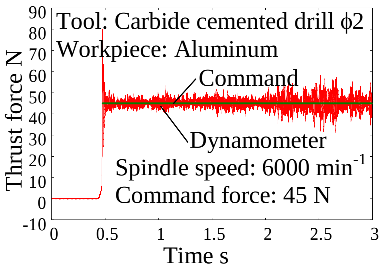


Figure 7: Controlled thrust force

5 Conclusion

Thrust force control applying a sensor-less cutting force monitoring method is proposed and the validity is confirmed. In future works, we will apply the method to drill composite materials and evaluate the relationship between thrust force and machined surface.

Acknowledgements

This study was supported by Industrial Technology Research Grant Program in 2009 from New Energy and Industrial Technology Development Organization (NEDO) of Japan.

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