Measurement 85 (2016) 65–79

Contents lists available at ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement

Cutting force analysis to estimate the friction force in linear guideways of CNC machine

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ARTICLE INFO

Article history:
Received 20 May 2015
Received in revised form 4 January 2016
Accepted 16 February 2016
Available online 23 February 2016

Keywords:
Machine tools
Motion
Linear guideways
Cutting force
Friction force

ABSTRACT

Linear guideways are widely applied in advanced machinery industries worldwide for different types of CNC machine (e.g., turning, milling, grinding, and gantry). All of these machines require accuracy and precision in the machining operations to manufacture quality products. The cutting operation in product manufacturing occurs with the displacement of machine tables on linear guideways. For this reason, linear guideways are significant parts and have sensitive locations in CNC machines to yield precision and accuracy. Friction is a major factor of deformation in guideways and non-smooth motion that prevents superior accuracy and precision in machine operations. Moreover, the frictional behavior in linear guideways is one of the most crucial challenges for CNC machining, such that between two parts of friction and temperature stimulus there will be stick-slip motion, wear and corrosion of the parts. Thus, manufacturers are interested in these machines, particularly to facilitate this process with an actual lubrication system. Hence, friction force estimation and modeling in CNC machine guideways is used to overcome these problems by controlling the lubrication operation.

In this research work, the cutting force components including, longitudinal force (F_L), radial force (F_r) and tangential force (F_t) are measured during cutting process. These cutting force values are corresponding to different cutting conditions includes, spindle speed, depth of cut, and feed rate. The cutting force components and the weight of the moving parts are analyzed and transferred to the CNC machine guideways. The friction force on linear guideways of machine tools is modeled based on the analyzed and transferred force components on the guideways during cutting. The static and kinetic coefficient of friction are measured experimentally in dry lubrication condition hence the friction force components can be obtained. The friction force are estimated using the identified coefficient of friction.

1. Introduction

Guideways are among the most critical elements in machining tools, as they guide the tool or work piece along a predetermined path [1], usually in a straight line or circle [2]. Guideway wear along with thermal and vibration errors are the largest contributors to positioning and dimensional workpiece errors in precision machining. For

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http://dx.doi.org/10.1016/j.measurement.2016.02.017
0263-2241/

instance, machine tool carriages typically operate on slideways under high loads and slow speeds and thus must be able to get into motion quickly and smoothly and then continue at a constant speed.

According to Fig. 1, friction between contact points in linear guideways and carriages is problematic for achieving machining precision and accuracy. Temperature increases due to friction; consequently, friction is usually considered in motion control design for the sake of simple implementation [3–10]. However, the slideways generally used in the feed drive servomechanisms of CNC machine tools often induce significant static friction [11–13]. Static friction cannot be ignored in practical applications because it can significantly deteriorate the reversal motions of feed drive servomechanisms.

The frictional behavior in linear guideways is one of the most crucial challenges with CNC machining, as higher friction produces motion and accuracy problems. Lubrication in CNC machine guideways is used to overcome such problems. According to Fig. 2 [14], lubricated sliding surfaces exhibit frictional behavior. The oil viscosity (η), sliding speed (v), and the average normal force on the plane of projection (N), cause the frictional coefficient (μ). In zone I, a solid-to-solid contact between guide surfaces is seen, since the oil film thickness is less than the surface roughness. Although the oil film prevents total seizure, partial seizure can occur as conditions approach boundary zone I. This field is called boundary lubrication state. In zone III, the oil film is much thicker than the surface roughness and prevents solid-to-solid contact. This is called the hydrodynamic lubrication state. Field II indicates a middle stage called the mixed lubrication state. Hence applying correct lubrication condition is very essential for getting higher motion precision with lowest oil consumption.

Currently there are two lubrication techniques are used, including manual and automatic lubrication were used for lubrication of carriages in CNC machines to overcome the frictional behavior in linear guideways. Manual lubrication was based on the provided instructions of the CNC machine maker company, and is performed by the operator. This method does not guarantee correctness, amount, or controlled lubrication, as it depends on operator experience. On the other hand, automatic lubrication process runs based on a fixed time and amount of oil injection regardless of cutting force value, weight and size of the workpiece, friction force on the guideways, and machining process conditions. This leads to less protection of the guideways in case there is high friction force, or excessive oil consumption at lessen the friction force in guideways. Manual and automatic lubrication methods can be used independently or together based on the design provided by the machine makers [15,16].

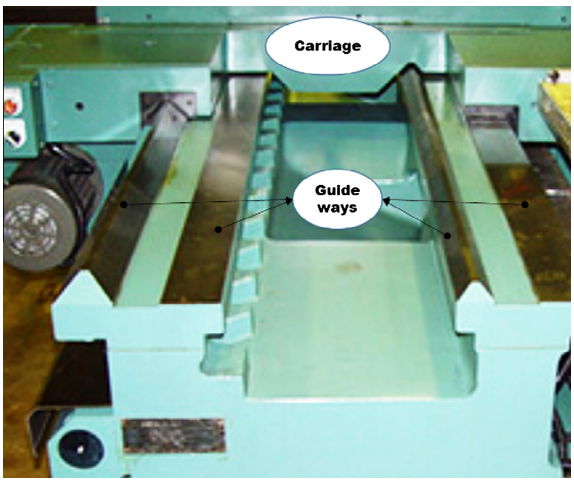

Fig. 1. Contact points in linear guideways.

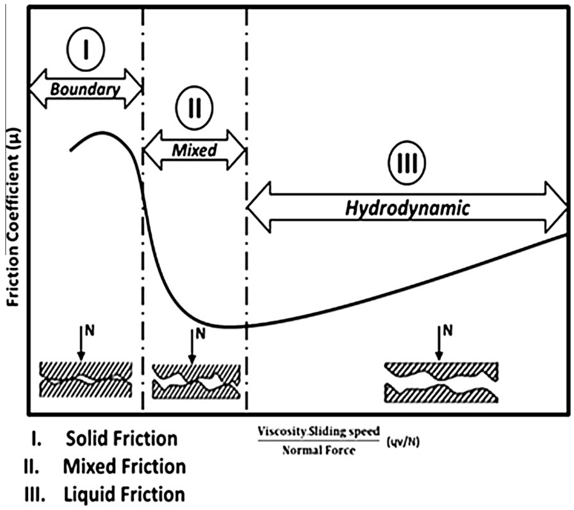

Fig. 2. Schematic representation of the Stribeck diagram.

The most important matter in this research is the quality of correct lubrication. This paper then emphasizes the effects of cutting components [17] on friction modeling for a systematic approach of lubrication after which the new control technique with intelligent lubrication system in a CNC machine will introduced in future.

Many researchers have analyzed the frictional behavior of machine components, and some work has been carried out on practical machine tools. To simplify the stick-slip procedure, Kato et al. studied the characteristics of static friction during sticking and kinetic friction during slipping [18]. However, static friction is position-dependent [19] and the interplay of moving parts in a transmission system can considerably affect the position dependency of static friction [20].

Friction occurs in all machines possessing relative motion and is salient in many servomechanisms and simple pneumatic or hydraulic systems. Realistically speaking, friction can lead to tracking errors, limited cycles, and undesirable stick-slip motion [21]. Engineers have to deal with the undesirable effects of friction, and the lack effective tools make it all the more severe [22,23]. In order to overcome this problem and achieve a high performance of servo control systems, an appropriate friction model [24] to describe the friction characteristics is required. The LuGre model [25] is representative of such model. Researchers have utilized this model for it possesses a sim-