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Contact mechanics applied to the machining of thin rings

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Abstract

Precision machining of thin rings is of key importance in the performance of many mechanical components such as bearings, rings, turbines, etc. An important factor to take into account is to know the influence of the clamping forces values at different angular positions of the workpiece in the geometrical tolerances after machining. The lower the clamping force, better tolerances will be achieved, but with the disadvantage of reducing friction force and, therefore, increasing the risk of slipping. Therefore, achieving a minimum but safe clamping force is a key factor to control the process. This paper presents some contributions of contact mechanics to the determination of an optimum clamping force. A subsequent methodology is applied that takes into account model of bulk deformation and local contact stresses and experimental data with the object of obtain the optimum torque applied to the chuck.

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Keywords: Contact Mechanics; Turning; Thin Rings; Chucks; Friction coefficient.

1. Introduction

The design of lathe chucks to hold the thin ring workpieces takes into account the calculation of the minimum limit clamping force to be applied, thus provoking the minor possible effect on deformation, and therefore on the part precision loss [1], especially if these are slender as the case of thin rings [2, 3], which are common parts in gearboxes, motors, gear rims, pulleys, etc. These rings are required with a high degree of roundness and tight tolerances. The

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clamping forces of the jaws over a highly flexible ring cause a ring deformation that creates roundness errors in the part. The lower the clamping force, better tolerances will be achieved, but with the disadvantage of reducing friction force and, therefore, increasing the risk of slipping. However, if the clamping force decreases below a minimum limit, the detachment of the workpiece could occur, which what can lead to serious accidents [4]. Therefore, achieving a minimum but safe clamping force is a key factor to control the process.

Another factor to take into account is the spindle speed, as it increases, the camping force decreases as a consequence of centrifugal forces, and the dynamic response of the system affects also the cutting process [5, 6]. Therefore, the clamping force must overcome factors such cutting forces, centrifugal forces, bending moments [7], vibrations [8], etc.

Usually, the rings are made in lathes that have concentric plate clutches and these are fixed mechanically by wrenches or hydraulically through the control of pressure by solenoid valves. In order to measure the clamping forces, there exist load cells, but these sensors are expensive and difficult to assembly. Due to the disposition of jaws, and the concentric mechanism, the three-jaw chuck is the most common kind of fixture for these components. There are some specialize fixtures for thin rings as the six-jaw chuck and the use of segmented jaws but they have some inconveniences as the hyperstaticity, the lack of flexibility, the expensiveness, etc.

In the literature, some formulations and methods are provided for calculations of stresses and deformation in rings placed on lathe chucks. The most common method is the use of the Finite Element Method (FEM) [9], but it has a high computational cost because it requires a fine mesh to achieve sufficient precision. One analytical method is developed by Malluck and Melkote [10] based on some formulae of an old book from which the expressions of the internal moment and the ring deformation are deduced. This method was checked experimentally and with the Finite Element Method (FEM).

Since the analytical method is quicker than that of the (FEM), many papers are based in this. For example, Kurnady et al. [11] used it in optimization of the machining operation. Sölter et al. [12, 13], used it in a model to predict errors using different fixturing strategies. Stöbener et al. [14] used it as an analytical tool to study different strategies such as ultrasonic sensing and the use of Fast Tool Servo for the compensation of errors in real time. Soleiman and Mehr [15] use this approach also, etc.

In order to avoid the above mentioned problems, in this paper the numerical and analytic calculation to obtain the contact stresses within the jaw-workpiece contact zone described in [16] is applied with some improvements such the calculation of the rigidity of jaws and the reaction in jaws to the cutting force, which is presented in this paper. A simple and economical integrating method is proposed, which reduces on the one hand, the 6 unknowns to 3 of the hyperstatic problem, taking into account the rigidity of the jaw-piece system, seen in [16]. Another the drawback of simplified calculation of Melkote [10] is due to suppose the reaction of the jaws in a point, which causes peaks of tension in the results that are not real, but through an area which depends on the geometry and elastic constants, so contact mechanics theory must be applied in order to get the real stresses in this zone as is done in this paper.

Moreover, in this paper the local stresses are evaluated through the contact mechanics applying Hertz for small contact, and the method developed by Carrero-Blanco [17] for large contact, where the contact width is in order of magnitude of the radius such as in segmented jaws. The use of contact mechanics theory, therefore, limits the value of the moment and allows superimposing the global tensions calculated by Castigliano’s theorem [16] with the local tensions calculated by contact mechanics [17].

Another important factor of contact mechanics analyzed in this study is the calculation of adherent friction. The Coulomb´s coefficient of friction cannot be assumed, because the materials and the state of the surfaces vary, so it is advisable to obtain experimental friction coefficient directly through a simple test in the same conditions of contact jaw-workpiece as in the turning operation. In this paper the method is presented and the friction coefficient of several materials have been calculated from data obtained from the instrumented ring presented in [18] and the use of several dynamometric wrenches. The clamping force on the jaws can vary with the tightening torque applied, so a method is proposed to obtain both, the multiplier factor k and the coefficient of friction μ. The knowledge of μ, will allow to obtain the Cattaneo´s stick-slip zone pressures [19] and the subsequent map of subsurface stresses [20] that will superimpose the global stresses only when the contact area is small and large stresses.