Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 132 (2015) 639 – 646

Procedia Engineering

www.elsevier.com/locate/procedia

The Manufacturing Engineering Society International Conference, MESIC 2015

Thermal Simulation of Laser-assisted Turning

J.I. Arrizubieta[a,]*, F. Klocke[b], S. Gräfe[b], K. Arntz[b], A. Lamikiz[c]

[a] *"La Caixa" Foundation Scholarship holder. Department of Mechanical Engineering. University of the Basque Country UPV/EHU. Alameda Urquijo,s/n, 48013-Bilbao-Spain.*

[b] *Fraunhofer Institute for Production Technology IPT. Steinbachstrasse 17, 52074 Aachen. Germany*

[c] *Department of Mechanical Engineering. University of the Basque Country UPV/EHU. Alameda Urquijo,s/n, 48013-Bilbao-Spain*

Abstract

Laser-assisted turning is a technology that combines turning and laser heating in order to manufacture hard and difficult to machine materials. The laser is used to heat up the part in the cutting zone directly in front of the cutting tool, thus the material strength is reduced and the cutting forces decreased. By means of the usage of a pyrometer, it is possible to measure the temperature at the surface of the part. However, the temperature field inside the part to be manufactured depends on e.g. cutting velocity, heat conductivity and absorptivity and cannot be measured by a pyrometer.
The determination of the correct laser power and the distance between the laser spot and the cutting tool is necessary to ensure a suitable heating of the cutting zone and especially the temperatures reached at the different depths. With this objective, a thermal analysis of the process has been carried out a numerical model developed by the UPV/EHU.

Peer-review under responsibility of the Scientific Committee of MESIC 2015

Keywords: Laser; Modelling; Thermal field; Laser-assisted turning.

1. Introduction

In order to fulfil the market requirements and achieve the same performance with a lower weight (fuel saving, more space available, etc.), new and harder materials are required. The problem that involves the usage of these new materials is that they need to be manufactured, what in many cases results to be an almost out of reach task.

* Corresponding author. Tel.: +34-94 601 3932; fax: +34 94 601 4215.
E-mail address: joninaki.arrizubieta@ehu.es

Peer-review under responsibility of the Scientific Committee of MESIC 2015
doi:10.1016/j.proeng.2015.12.542

This is especially critical when ceramic materials are needed to be manufactured. Their brittle nature together with an extremely high hardness makes almost impossible the conventional turning of these materials. Although ceramic materials can be shaped by means of sintering, when a finishing operation is needed after the sintering process in order to achieve a determinate shape, dimension or surface quality, usually a last grinding step is used [1, 2]. Even if grinding can produce good surface quality and geometric tolerances, its lack of flexibility and low material removal rate make this process unattractive [2].

Laser-assisted turning (LAT) has arisen as an alternative to the grinding process of these hard to manufacture materials. During the last decade, several authors have demonstrated the viability of the LAT process [3-6].

In LAT operations, the material is locally heated by a laser beam directly in front of the cutting tool [2]. Hence, as the material is heated up in the cutting zone, the material hardness and strength are lowered and thereby the cutting forces are reduced resulting in an increase of the machinability [7-8].

With the aim of predicting this thermal field and therefore determine the correct position of the tool regarding to the laser spot along with the determination of the maximum cutting depth for a determinate laser power, several numerical models have been developed. For example, authors like [9] propose a 3D thermal model that calculates the transient temperature field including material removal, what means a continuous geometry change.

In order to validate the developed models, there are different options. Authors like [9] used infrared camera measurements to validate the model results. Whereas, others like [10] used discrete pyrometer measurements at different points of the surface.

In the present paper, a 3D numerical model that simulates the thermal field in a rotational part heated by a laser beam has been developed. The model enables to determine the maximum temperatures reached and also helps to determine the optimum distance between the laser beam focus point and the cutting tool position. Furthermore, the model enables to determine the adequate cutting depth according to the most suitable cutting conditions.

For this purpose, the thermal model LATHEM (LAser THErmal Modelling) developed by the University of the Basque Country has been used. The model solves the general equation of the temperature field for the conduction situation when the part is heated by a laser beam. Afterwards, the model has been validated according to the different pyrometer measurements during the LAT process tests carried out using the laser hybrid machine tool Monforts RNC 400 LaserTurn at Fraunhofer IPT (Aachen, Germany).

2. Numerical model

The simulations have been carried out using the thermal model LATHEM developed by the University of the Basque Country. As in the LAT process no melted material is allowed, the model does not take into account the viscous phenomena and just solves the thermal conduction equation.

For this purpose, the program discretizes the geometry using finite elements and solves the Fourier law for the heat conduction (the first law of thermodynamics). The energetic evaluation on a differential element (see Fig. 1) can be expressed by the equation (1), where the difference between the amount of energy exchanged with the environment (E_{IN}-E_{OUT}) and the generated energy ($E_{GENERATION}$) equals the element energy variation ($E_{VARIATION}$).

$$dE_{IN} - dE_{OUT} + dE_{GENERATION} = dE_{VARIATION} \qquad (1)$$

Using the Laplace operator and supposing that the conduction coefficient is constant (independent from temperature), the difference between the energy that gets into the element and the energy that goes out, can be expressed with the following equation (2). Where "k" is the conductivity coefficient [$W\ m^{-1}\ K^{-1}$], "T" is the temperature value [K], "dV" is the element volume (dV = dx · dy · dz) [m^3] and "dt" is the time step [s].

$$(dE_{IN} - dE_{OUT}) = -k \cdot \left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}\right) \cdot dV \cdot dt = -k \cdot \nabla^2 T \cdot dV \cdot dt \qquad (2)$$

The generated energy is defined in equation (3), where "q_v" is the introduced power per volume unit [$W\ m^{-3}$]. It takes a positive value when energy is introduced into the analysed volume (in case the laser is heating up the element) or a negative value when there is an energy drain (radiation and convection losses).