The idea of a robotic single-sided lapping system

This paper reviews the idea of a robotic lapping system. Robot’s assistance automates the lapping process and supports the development of a flexible lapping system. However, the main aim behind the idea of a robotic lapping system is to provide improved means for controlling the position of conditioning rings on a lapping plate. Due to the kinematics of lapping process, the profile wear of the tool is not constant along the radius. Changing the kinematic parameters, e.g. position of the conditioning ring with the working elements or rotational velocities of the lap and the ring can be used for correction of surface’s profile in the lap as well as for avoiding undesirable convexity or concavity. Lapping plate flatness has an essential influence on the shape accuracy of lapped surfaces. Flatness of the lap during its contact with the abrasive grain in the lapping process was studied.

Key words: flat surfaces, single-plate lapping machines, industrial robots

1. INTRODUCTION

Lapping is a significant technology in a number of precision manufacturing processes. It is widely used in technical ceramics, medical devices, electro optics, data storage, aerospace and automotive industries. This type of machining can also be used in optical mirrors and lenses [2]. Lapping is performed by applying loose abrasive grains between two surfaces and causing a relative motion between them, resulting in a finish of a multi-directional layer. The most commonly used type of the lapping process is flat lapping. Its aim is to achieve extremely high flatness of machined work piece or close parallelism in double-sided lapping. Single-sided lapping machines are usually used in conjunction with conditioning rings, which are set properly between the centre and the periphery of the lapping plate [1].

Previous research has focused primarily on mechanisms of material removal [4], effects of input parameters [10] and thermal measurements [7]. The main objective of most studies is to optimize the machining conditions in order to improve the surface quality and to increase the efficiency of the process. The

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behaviour of lap flatness in lapping process, when the standard input parameters – relative velocity of a work piece, as well as velocity of lapping plate – are carefully controlled and a conventional kinematic system is changed, has not been extensively investigated. Exploration of new kinematic systems is crucial due to its influence on flatness of lapping plate and, consequently, on the surface quality of a work piece.

The objective for robotic lapping system is to provide improved means for controlling the position of conditioning rings on lapping plate so as to enable the flatness of the plate to be controlled. This is an innovative solution that allows to fully automate a single-sided lapping process. Robot assisting helps to automate the lapping process with such options as multi-step programmable rings’ speed, pressure, slurry feed, and quick loading and unloading of the machine.

2. KINEMATICAL FUNDAMENTALS

2.1. Introduction

The single-plate lapping machines are finding an increasing range of applications. In most cases, single-sided lapping machines are based on a conventional executive system (Figure 1a). Conditioning rings (5) move on the working surface of the lapping plate (1) with rotational speed $n_s$. The lap rotates with rotational speed $n_t$ and drives conditioning rings, where separators (4) are placed, allowing for additional move of work pieces (3). Due to the force of friction, conditioning rings cause a torque. They rotate with speed dependant on: the speed of the lapping plate, friction conditions in the work piece-tool contact zone and radial position ($R$), which can be controlled with roller forks (2). Fatigue of work pieces is caused by pneumatic systems or weight. In order to ensure an even distribution of the load, it is exerted through a felt pad [1].

There are four main factors which influence the quality of the lapping process. It should be noticed that the flatness of the lapped surface is theoretically a copy of the lap, which is uniformly kept flat by the conditioning rings. The flatness of the pressure plate or interchanging of the work pieces ensure the parallelism and dimensional continuity of work pieces. The next factor is the size accuracy achieved by precisely controlled removal rate per unit of process time. Furthermore: the grit type, lapping fluid (film) and pressure determine the surface finish of work pieces [9].
The idea of robotic single-sided lapping system

Kinematics forces of lapping have a crucial influence on the surface flatness. In order to model a lapping plate wear, a comprehensive analysis of lapping kinematic equations must be provided. The position of any point P belonging to a work piece must be determined. It can be done by a radius vector in two coordinate systems: absolute $\zeta-\eta$ and relative $x-y$, which is related with rotating lapping plate (Figure 2b). The coordinates $x_p$ i $y_p$ are functions of time and can be determined:

\[
x_p(t) = R \cdot \cos(-\omega_t \cdot t) + r \cdot \cos(-k \cdot \omega_l \cdot t)
\]

\[
y_p(t) = R \cdot \sin(-\omega_t \cdot t) + r \cdot \sin(-k \cdot \omega_l \cdot t)
\]

where:
- $t$ – any moment of lapping,
- $\omega_t$ – angular velocity of lapping plate,
- $\omega_l$ – angular velocity of conditioning ring,
- $R$ – distance from the centre of the lapping plate to the centre of conditioning ring,
- $R$ – distance from the centre of conditioning ring to the point P, $k = (\omega_k - \omega_l)/\omega_l$ – speed ratio [3].

The instantaneous speed $v_p$ and acceleration $a_p$ of the point P equal:

\[
v_p(t) = \omega_t \cdot \sqrt{R^2 + k^2 \cdot r^2 + 2 \cdot r \cdot R \cdot k \cdot \cos(-\omega_t \cdot t)}
\]

\[
a_p(t) = \omega_t^2 \cdot \sqrt{R^2 + k^4 \cdot r^2 + 2 \cdot r \cdot R \cdot k^2 \cdot \cos(-\omega_t \cdot t)}
\]
2.2. Path types analysis

Equations (1) and (2) are used to determine cycloid paths of any point. These paths can be treated as areas where the lapping plate deteriorates by a grain placed in a specific location of a conditioning ring or work piece. Darker areas are the measurements of density of trajectories and thus the amount of material removed on the lapping plate. It is clear that by choosing appropriate kinematical parameters, tool’s wear can be controlled.

Based on the ratio of a conditioning ring and a lapping plate velocities an additional parameter was defined:

\[
k' = \frac{\omega_s}{\omega_t}
\]  

(5)

After detailed analysis and simulations, it can be observed that the value \(k'\) determines the type of trajectories (Figure 2). When \(k'\) is lower than 0, the epicycloid paths are drawn. With the value is close to 0, stretched epicycloids can be received, which consequently overlap. Between values 0 and 1, pericycloids appear. With \(k'\) higher than the value of 1 the pericycloid transforms into hypocycloid. Initially, it is a stretched hypocycloid, which afterwards transforms to interlaced hypocycloid.

Figure 2. Path types depending on the rotational speed ratio \(k' = \omega_s/\omega_t\)
2.3. Unconventional lapping kinematics

After a careful analysis of an extended research and numerous offers from lapping machines producers, it has been determined that most of the lapping machines have a standard kinematic system, where conditioning rings rotate only around their axes. Figure 3 provides unconventional lapping systems. In this idea, the conditioning ring performs additional moves: radial (Figure 3a), secant (Figure 3b), swinging (Figure 3c) or off-centre (Figure 3d). Simulation has shown that a change in kinematic system causes a wide variation of trajectories density [8]. Figure 4 shows trajectories and expected wears of the lapping plate for different velocities of the conditioning ring along a secant of the lap.

Figure 3. Examples of unconventional lapping systems a) radial, b) secant, c) swinging, d) off-center

Figure 4. Paths observed in secant lapping system: \( n_r = 14 \text{ rpm}, \ n_s = 11 \text{ rpm}, \ t = 120 \text{ s}, \ R = 180 \text{ mm}, \ r = 90 \text{ mm} \) and a) \( v_1 = 0 \text{ mm/min} \), b) \( v_1 = 500 \text{ mm/min} \), c) \( v_1 = 1000 \text{ mm/min} \), d) \( v_1 = 1500 \text{ mm/min} \)
3. ROBOTIC LAPPING SYSTEM

3.1. Flexible lapping systems

Nowadays, modern lapping machines become more efficient as the basic constructions are supplied with additional components. As a result of the automation of lapping machines, some of the supporting operations were eliminated. Lapping machines for flat and parallel surfaces are supplied with feeding tables, loading and unloading systems of rings which virtually form mini-production lines.

Deserving attention are lapping machines produced by Lapp-Technik A.W. Stahli A.G. The company offers lapping machines which are equipped with belt conveyors for work pieces (Figure 5a). Another solution is an automatic single-plate lapping machine (Figure 5b). A turntable (1) with loading device (2) was attached to a traditional lapping machine (3). The table has five stations. In position I, work pieces are changed and the loading device inserts the conditioning ring. Then, after a lapping process, the conditioning ring is inserted to the inverting place, allowing the work piece to be lapped in another ring and along to the other side. Positions III, IV, V are used for replenishing and retrieving the work piece from the ancillary table [6].

The Peter Wolters company offers micro lapping lines that provide greater efficiency and precision (Figure 4). However, these machines are double-sided lapping machines. They can be equipped with loading tables (Figure 6a) or with robots (Figure 6b). A five-axis robot functions as a work pieces’ feeder. The
The idea of robotic single-sided lapping system

Figure 6. Peter Wolters lapping machines equipped with: a) loading table, b) robot [5]

The robot is able to transport the work pieces from the storeroom with a magnetic or vacuum holder, place them in the carrier wheels and shift. The system reduces the auxiliary process time, increases the flow capacity and enables for an unmanned machining process [5].

3.2. Idea of a robotic lapping system

After careful analysis of numerous offers of many lapping machines producers, it has been verified that none of them utilizes a system where the ring is led by the manipulator during the machining. The robot functions as a feeder in the Peter Walters lapping machines (Figure 6b) and, moreover, it has the ability to support machining. It is complicated and in some cases impossible to create a universal mechanism that leads the ring along any path. As a result of the robot moving the effector from point to point, it is possible to change the ring’s trajectory at any moment – which enables to apply any kinematics of lapping, which will cause a regular wear of lapping disc at its ray.

The idea of a flexible single-sided lapping system, assisted by a robot, is presented in Figure 7. Firstly, the work pieces need to be sorted (Figure 7a), which are then transported from the table to a separator, located in a conditioning ring (Figure 7b). Afterwards, the ring is gripped by the robot and situated next to the lapping paths on the plate, which is propelled with angular velocity \( \omega_r \). Machining is executed by the robot (Figure 7c). It shifts the ring with work pieces in such a way to keep the flatness of the plate along the radius. The turning motion \( \omega_s \) of the ring can be forced by the robot (in the same or opposing rotational direction), or it can be affected by the friction force. After the lapping process, robot shifts conditioning ring to another table and work pieces are removed as final products (Figure 7d). Finally, the flatness of the plate is controlled and can be fixed in case an error occurs.
Figure 7. Idea of robotic single-sided lapping system: a) work pieces sorting, b) work pieces loading, c) robot assisted lapping process, d) separator unloading

4. CONCLUSIONS

Nowadays, more and more requirements for applied sciences are encountered. Conventional methods of machining are lacking in technological advancement as their level of precision is not efficient. The aim of this article is to present the idea of a robotic lapping system. One of robot’s tasks is to perform the operations of material handling. However, the most innovative method is a robot-assisted lapping process. Based on the simulations and analysis of various unconventional lapping systems it was observed that mesh density on a lapping plate varies when the running parameters and kinematics of a conditioning ring’s movement are changed. Kinematic systems that provide a constant wear along the radius of the plate are required for further advancement.
The idea of robotic single-sided lapping system

REFERENCES


KONCEPCJA ZROBOTYZOWANEGO SYSTEMU DOCIERANIA JEDNOTARCZOWEGO

S tre s z c z e n i e


Słowa kluczowe: powierzchnie płaskie, docieranie jednotarczowe, robot przemysłowy